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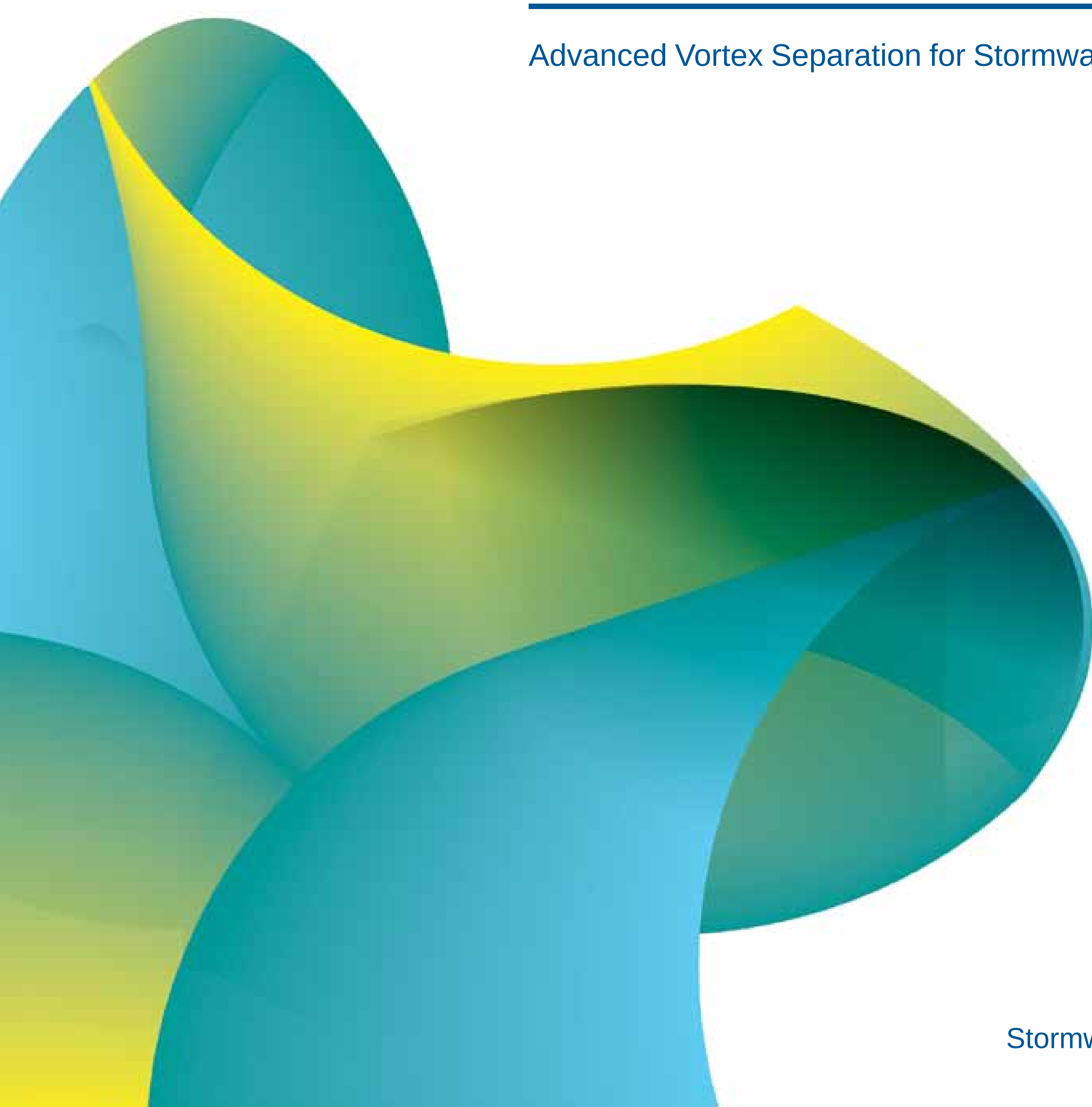
Hydro International®

HX Guide to the Downstream Defender®

Advanced Vortex Separation for Stormwater Treatment



Stormwater Solutions

www.hydro-int.com

Contents

Overview

Today, more manufactured stormwater treatment devices are available than ever before. The choices made by designers and specifiers of stormwater treatment devices have a huge impact on achieving stormwater treatment and water quality goals.

Although having such a wide selection of stormwater treatment devices gives engineers and site designers more "tools" in their design toolbox, it is important to understand that not all stormwater treatment devices are the same.

The purpose of this guide is to provide information about Advanced Vortex Separation technology and how its attributes make it well suited to a wide variety of stormwater treatment applications, development types and site conditions. This guide will go deeper into the science behind Advanced Vortex Separation, explaining the commonalities and differences between gravity separation, basic vortex separation and benefits of Advanced Vortex Separation.

What is HX?

HX stands for "Hydro Experience". It is inspired by our passion for engineering innovation and our commitment to sound science.

Pushing the boundaries of water management technology has been the heart of what we do for more than thirty years.

Hydro HX is a mark of our commitment to quality and our dedication to achieving optimum performance.

There is no equivalent to HX.

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Who is this guide designed for?

- Consulting Engineers
- Developers
- Landscape Designers
- State & Local Authorities
- Stormwater Scientists

I. Introduction to Advanced Vortex Separation

Hydrodynamic vortex separators are high rate, rotary flow solids/liquid separation devices used worldwide for a variety of water quality applications. Advanced Vortex Separators are a specific class of hydrodynamic separator.

Key Features of Advanced Vortex Separators

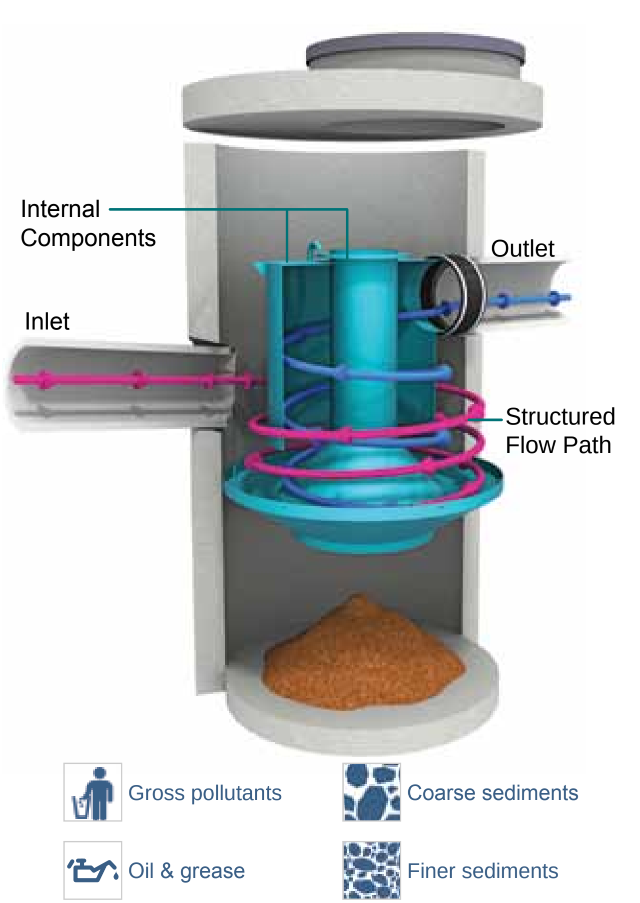
To be considered "advanced vortex" technology, a separator must have three essential features:

- A stabilized rotational flow regime
- A structured three dimensional flow path
- A means to prevent washout of captured pollutants

Advantages of Advanced Vortex Separation

- Particles settle faster in Advanced Vortex Separators
- Advanced Vortex Separators capture and retain a wider particle size range than other hydrodynamic and vortex separators
- Advanced Vortex Separators prevent re-release of captured pollutants during high-flow storm events
- Advanced Vortex technology results in lower headloss and higher treatment in a smaller, more economical footprint
- Advanced Vortex Separators are as easy and economical to maintain as typical catch basins

Fig.1 Downstream Defender® Advanced Vortex Separator



The Downstream Defender® Advanced Vortex Separator

The Downstream Defender® is one of a family of advanced vortex separators designed and supplied by Hydro International that utilize the principles of advanced vortex separation to remove Total Suspended Solids (TSS), trash and hydrocarbons from polluted water (Fig.1). The Downstream Defender® is specifically designed for stormwater treatment applications.

The Downstream Defender® includes flow-modifying internal components specially designed to facilitate advanced vortex separation. These components control, stabilize and enhance the effects of the rotary and shear forces in vortex flow to improve all-around performance.

Through Computational Fluid Dynamics (CFD) and full-scale testing, the Downstream Defender® has evolved from earlier generation vortex separators to address the technical shortcomings of simple swirl-type devices and conventional hydrodynamic separators. By reducing turbulence and headlosses, enhancing separation, and preventing re-suspension of previously stored pollutants over a wide range of flow rates, the Downstream Defender® is a versatile and cost-effective stormwater treatment device.

The Downstream Defender® has been shown to be a highly efficient stormwater treatment device. Since its introduction, the Downstream Defender® has been installed in thousands of locations across the US, Canada, Europe, Asia and South America.

II. Removing Solids from Stormwater with Advanced Vortex Separation

The solid pollutants in stormwater runoff vary widely in particle size range, density, toxicity and cost to treat. Many classes of structural Best Management Practices (BMPs) are required to target the entire spectrum of pollutants. Traditional hydrodynamic and vortex separators are used to capture gross and coarse solids. Advanced Vortex Separators treat a broader range of the spectrum due to the technical benefits of advanced vortex technology (Fig.2).

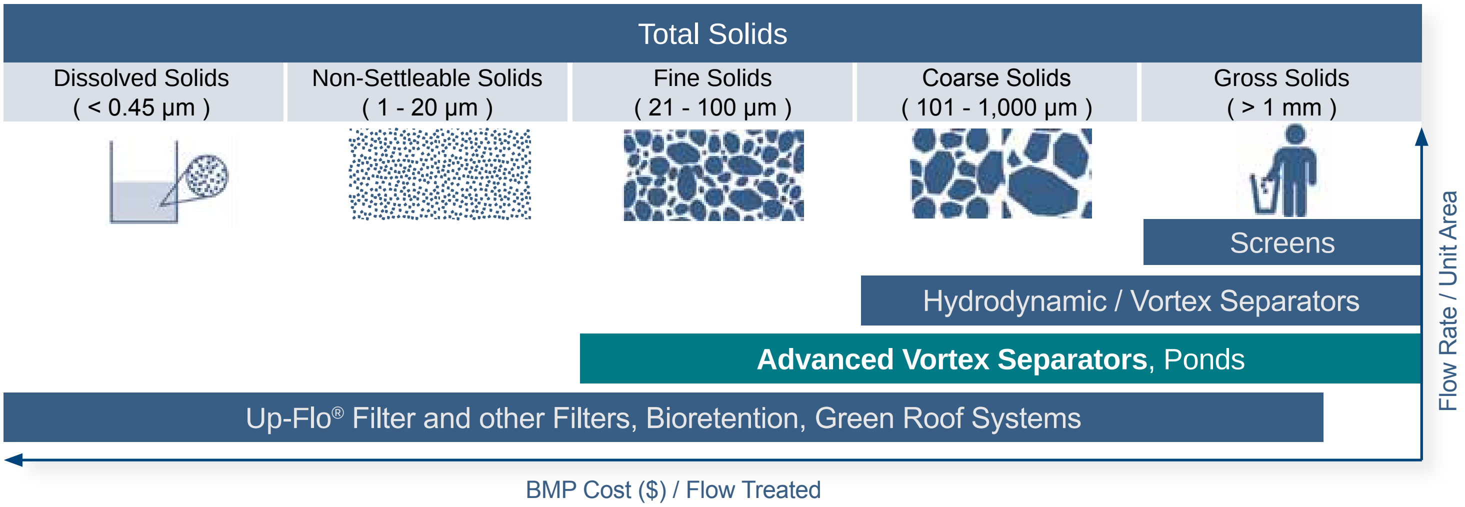


Fig.2 Advanced Vortex Separators treat a broader range of the Total Solids spectrum than conventional hydrodynamic and vortex separators.

A Field Comparison of Solids Captured in Various Hydrodynamic Separators

A 2006 study confirmed that Advanced Vortex Separators capture a wider range of solids than other hydrodynamic and vortex separators. Pollutants extracted from the storage sumps of various separators showed that material captured and retained in the Downstream Defender® is significantly finer than the solids captured by other devices (Fig.3).

The sump material of Downstream Defender® installations was found to be as fine as the material captured within large stormwater ponds (Faram et al., 2006).

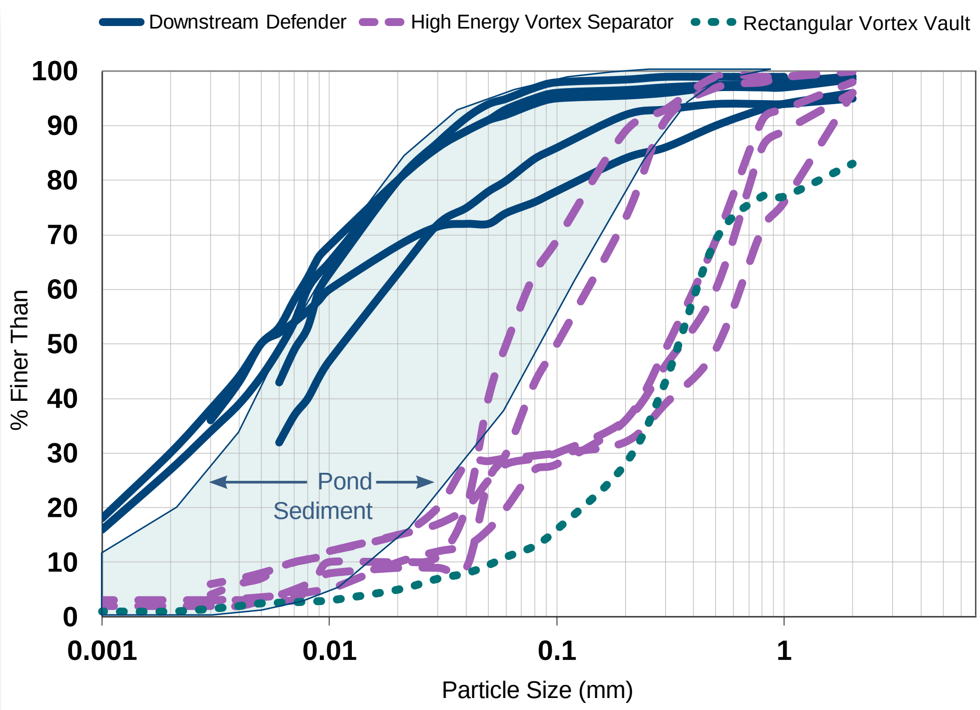


Fig.3 Solids captured in the Downstream Defender® have been shown to be finer than solids captured in other vortex separators and as fine as solids captured in ponds. Pond range limits from Marsalek et al., (2002) and Bentzen et al., (2005).

III. Stormwater Treatment Applications for Advanced Vortex Separation

Advanced Vortex Separator technology offers unique features and benefits, including high performance in a small footprint and low headloss. These distinguishing benefits make Advanced Vortex Separators well suited to a wide variety of applications, development types and site conditions.

Key Benefits of Advanced Vortex Technology

- Small footprint
- High treatment
- Low headloss
- Economical to install
- Economical to maintain
- Prevents pollutant washout
- Can treat a wide range of flows

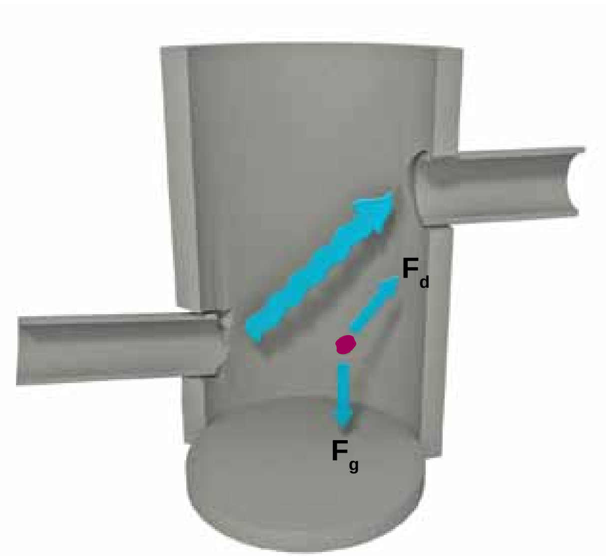
Stormwater Treatment Application		Why Advanced Vortex Separators Work for This Application
Treatment Level	Pretreatment	Pretreatment BMPs must be low headloss or there may not be enough drop on the hydraulic grade line for the downstream treatment device. They must prevent washout or else they put the downstream treatment device at risk of contamination and failure.
	Stand-alone Treatment	Stand-alone treatment devices must be able to provide a high level of treatment over a wide range of flows.
Site Size	Medium to Large	Larger sites generate larger flows, so treatment devices must provide a high level of treatment. They must also be economical since multiple treatment devices are often required.
	Small	Small sites often do not have space for larger treatment systems, nor the budget for expensive solutions.
Hydraulic Profile	Steep to Shallow	Steep grades cause high flow velocities that can cause scour velocities in other devices. High headlosses risk upstream flooding on a shallow grade line.
Development Type	Redevelopment	Redevelopment sites are often space constrained and expensive to develop, so BMPs must be compact and economical. Low headloss BMPs increase the possibility of using an existing storm drain line.
	New Development	New developments often have the most stringent and expensive standards to meet, so BMPs should be economical to install and maintain.
	Low Impact Development / Green Infrastructure	"Green" BMPs are not always practical on all areas of a site and cannot always be sized for the entire flow of runoff that must be managed.
	LEED® Developments	Certain treatment BMPs qualify for 1 LEED® Credit under Sustainable Sites Section 6.2.
	High Traffic / High Pollutant Load	Pollutant "hot spots" require high-performance treatment BMPs. Higher treatment levels mean a higher rate of pollutant accumulation within the BMP so maintenance must be economical.

IV. The Principles of Conventional and Vortex Separation

Review of Conventional Sedimentation

For decades conventional settling devices such as wastewater clarifiers and stormwater ponds have been the conventional technology used to remove solids from water. The mechanism of settling can be explained by Stokes Law, which defines a particle's Settling Velocity (Vs) as a function of particle density and diameter, fluid density and viscosity and the intensity of the acceleration field (Eq.1).

In conventional settling chambers, the significant forces acting on the particle are gravity and drag (Fig.4). Gravity acts to draw the particle downward, while drag draws the particle along the flow stream.



$$V_s = \frac{\delta\rho\,\gamma d^2}{18\mu}$$

Eq.1 Stokes Law, where:

V_s = Settling velocity

$\delta\rho$ = Density difference between the particle and surrounding fluid

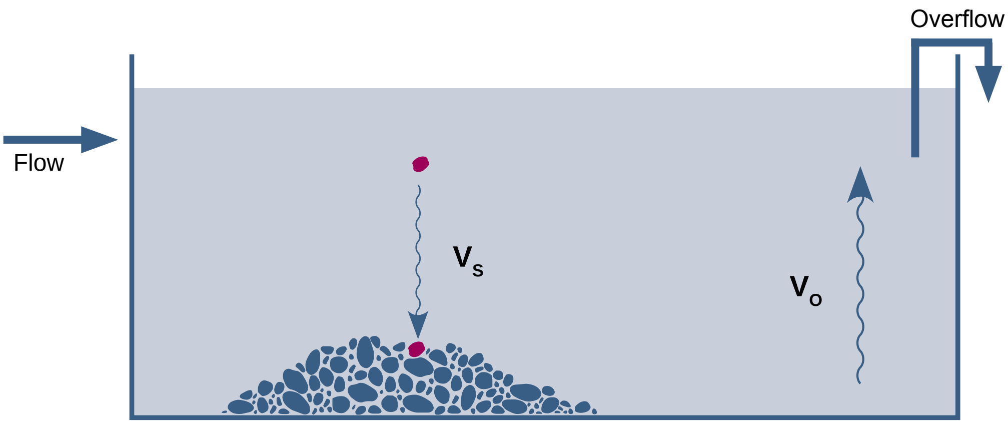
γ = Intensity of the acceleration field; a function of forces acting on the particle such as drag (F_d) and gravity (F_g)

d = Diameter of the particle

μ = Viscosity of the fluid

Fig.4 In conventional settling, the significant forces acting on a particle are gravity (F_g) and drag (F_d).

Conventional sedimentation operates according to the basic principles of settling whereby a particle settles out of the liquid when its Settling Velocity (V_S) exceeds the average overflow Rise Rate (V_O). See Fig.5. Rise Rate is explained by Eq.2.



$$V_O = \frac{Q}{A}$$

Eq.2 Overflow Rise Rate, where:

V_O = Overflow Rise Rate

Q = Flow rate

A = Area of sedimentation tank

Fig.5 Conventional settling works when the Settling Velocity (V_S) of a particle exceeds the overflow Rise Rate (V_O). Rise Rate is a function of flow and area.

Mechanisms of Vortex Separation

Vortex separators, like conventional gravity separation chambers, operate according to the fundamental principles of settling velocity. However, vortex separators benefit from the addition of vortex-induced inertial forces, such as centrifugal force (Fc) depicted in Fig. 6, that increase settling velocity.

The magnitude of vortex-induced forces can reach several times the force of gravity depending upon vortex chamber geometry and the flow path, velocity and mass of the particle (Eq.3).

Eq. 3 $$Fc = \left(\frac{mv^2}{r}\right)$$

Where:

Fc = Vortex forces
m = Particle mass
v = Particle velocity
r = Radius of flow path

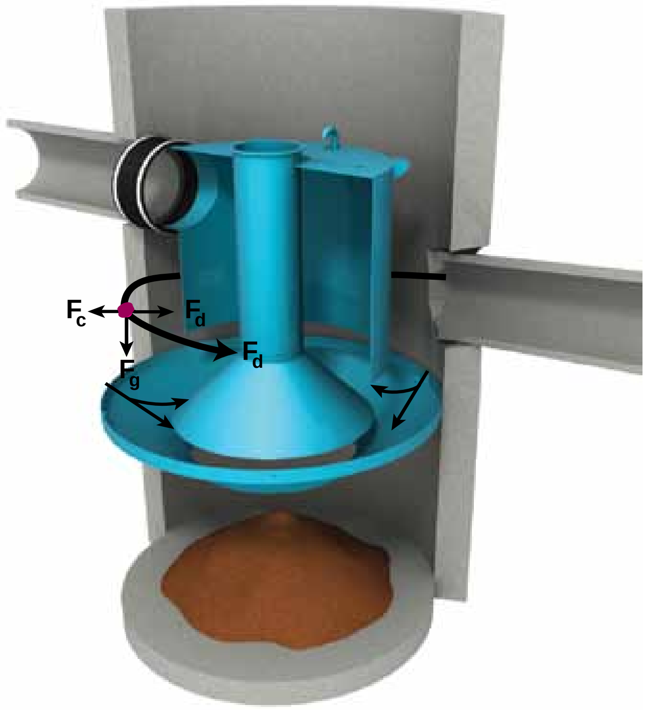


Fig.6 Vortex separators create additional forces (depicted as Fc) that increase the intensity of the acceleration field (γ), thereby augmenting gravity (Fg) to overcome drag forces (Fd) and increase the particle settling velocity (Vs) for enhanced settling performance.

Particles Settle Faster in Vortex Separators

The presence of additional rotary flow induced forces in a vortex separation chamber increases the intensity of the acceleration field (γ), thereby increasing settling velocity (Vs) as per Stokes Law (Eq.1).

This means that a given particle will actually **settle out faster** in a vortex separator than in a conventional sedimentation device, with all other conditions being the same.

This phenomena was observed in the 1970s during performance testing of the EPA's Swirl Concentrator, an early model of vortex separator used to treat combined sewer overflows (CSOs). Fig.7 shows that the Swirl Separator captured suspended solids faster than an equivalent conventional sedimentation chamber (Field, 1972).

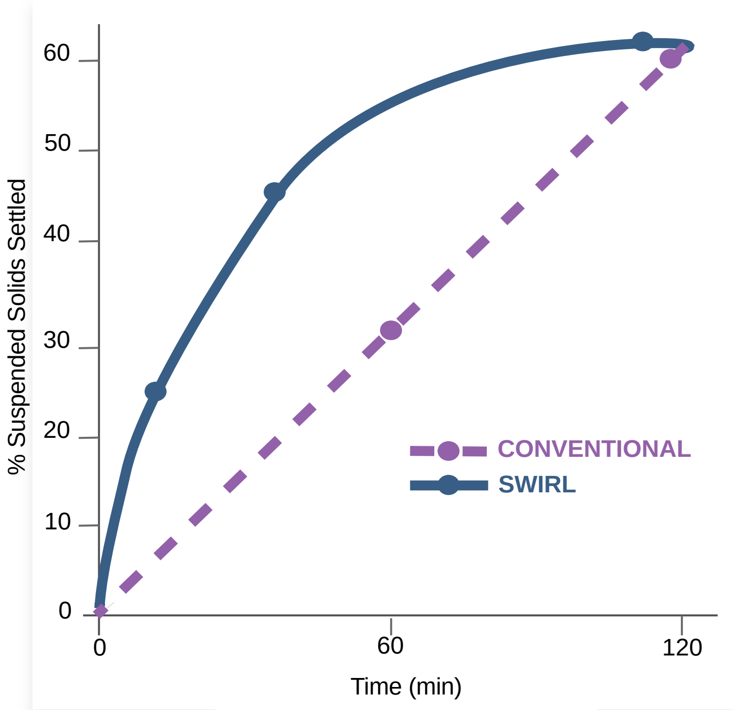


Fig.7 A comparison of time required to capture suspended solids in a swirl separator vs. a conventional sedimentation device, which showed that the bulk of settleable solids settled faster in the swirl separator (Field, 1972).

V. The Evolution of Advanced Vortex Separation

Early Vortex Separators

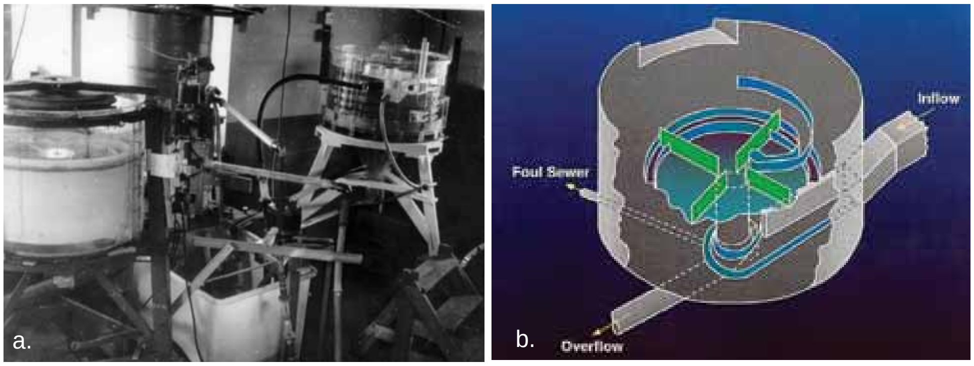


Fig.8 a) Smisson's early vortex separator prototypes under development in the living room of his home; b) The EPA Swirl Concentrator for CSO treatment was the first high profile vortex separator used for water treatment in the US.

Although the earliest references to basic vortex separators date back to the 1940s, they were not widely known in the water treatment sector until a researcher named Bernard Smisson pioneered the development of the US EPA "Swirl Concentrator" for Combined Sewer Overflow (CSO) treatment in the 1970s (Fig.8a,b).

The Swirl Concentrator was designed to meet the wastewater definition of "primary treatment" of 60% Settleable Solids removal. The pollutant storage sump returned collected solids to the sanitary sewer line via an effluent underflow connection. Fixed internal baffles induced vortex flow for high treatment performance but resulted in substantial headlosses.

Evolution of the Downstream Defender®

In the 1980s and 1990s, Hydro International's Research & Development group built on Bernard Smisson's pioneering work to develop the Storm King® Advanced Vortex Separator for CSO treatment and the Grit King® Advanced Vortex Separator for grit removal applications at wastewater headworks (**see more at www.hydro-int.com/us**).

In the 1990s when the US EPA enacted legislation that required MS4s to remove 80% of Total Suspended Solids (TSS) from stormwater runoff, Hydro expanded its family of Advanced Vortex Separators with the development of the Downstream Defender®, the first modern-day Advanced Vortex Separator for MS4 applications (Fig.9).

Modifications to make the Downstream Defender® ideally suited to MS4 applications include:

- Durable internal components designed to provide high treatment performance in a standard-size drainage manhole.
- Incorporating the "Dip Plate", a cylindrical floatables baffle that eliminates high headloss and prevents floatables from escaping during high flows.
- Incorporating an isolated sump, where pollutants are stored until routine maintenance is conducted with standard catch-basin cleaning equipment.

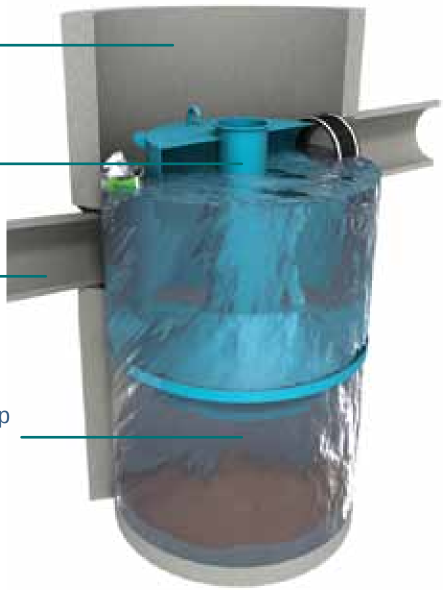


Fig.9 The Downstream Defender® was the first Advanced Vortex Separator designed specifically to treat stormwater in MS4 applications.

VI. Basic Vortex Separators vs. Advanced Vortex Separators

Essential Features of AVSs

Stable Rotational Flow Regime

3D Flow Path

Prevents Pollutant Washout

All stormwater separators are not necessarily "equivalent". To be classified as Avanced Vortex technology, a separator must incorporate three key features:

- A stabilized rotational flow regime
- A three dimensional flow path
- Pollutant storage zones that are isolated from the active treatment chamber

Internal Components are Key to Advanced Vortex Separation with the Downstream Defender®

The Downstream Defender® functions as an Advanced Vortex Separator because of its unique internal components (Fig.10).

The submerged tangential inlet introduces rotary flow while minimizing turbulence and headloss.

The Dip Plate Cylinder and Cone stabilize the flow and direct it along an elongated three-dimensional flow path.

The angled Cone and Benching Skirt convey settling pollutants into the Sediment Storage Sump and provide protection from scour and washout during high flows.

Downstream Defender® Components

1. Concrete Top Slab
2. Concrete Manhole
3. Dip Plate Cylinder
4. Submerged Tangential Inlet
5. Center Shaft and Cone
6. Benching Skirt
7. Maintenance Access Lids
8. Outlet Pipe
9. Oil & Floatables Storage
10. Sediment Storage Sump

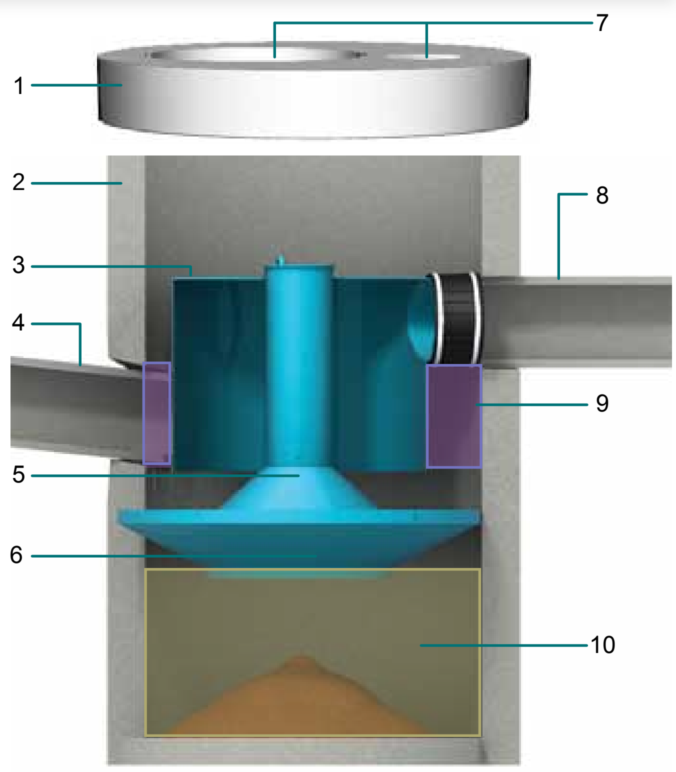


Fig.10 The specially designed components of the Downstream Defender® are the key to Advanced Vortex Separation.

Watch the Video to See How It Works

www.hydro-int.com/us/products/downstream-defender

Essential Features of AVSs

Stable Rotational Flow Regime

3D Flow Path

Prevents Pollutant Washout

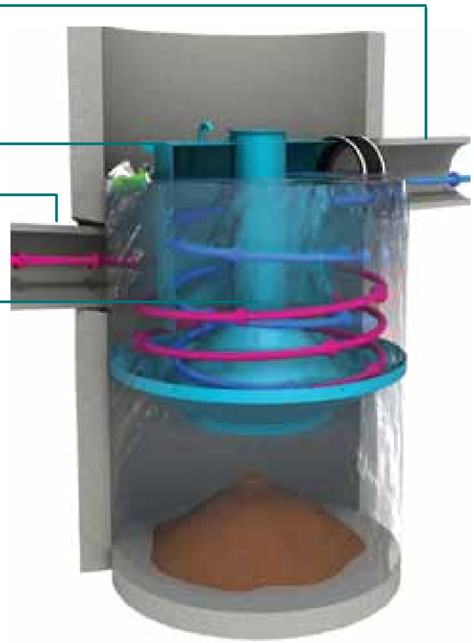
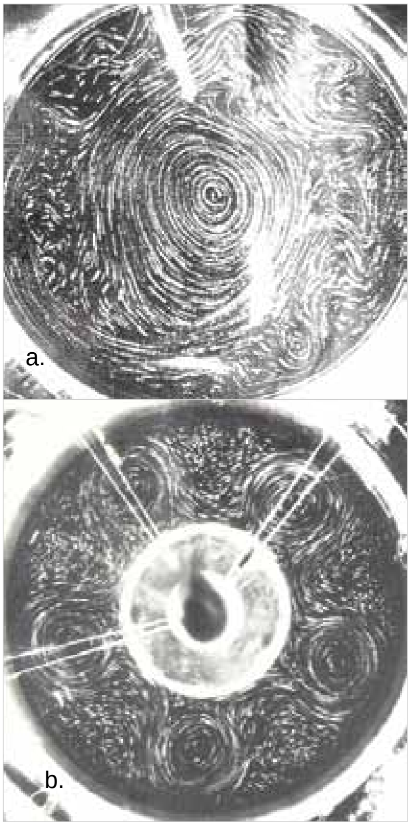


Fig.11 The flow-stabilizing components of the Downstream Defender® .

Benefits of a Stable Rotational Flow Regime

A stable flow regime reduces turbulence within the separator, which offers:

- Increased Pollutant Settling Performance
- Predictable Flow Path and Predictable Performance
- Reduced Headloss



The flow within basic vortex separators has been shown to be turbulent and chaotic. Unstable eddies and preferential flow paths quickly form and subsequently disappear. The flow therefore does not follow a predictable flow path (Fig.12a).

The unstructured turbulent flow reduces vortex separator performance. Turbulence impedes a particle as it is settling, keeping it suspended within the flow regime instead of settling. Turbulence also agitates sediment that has previously settled out, scouring it from the sump and resuspending it within the flow stream.

With the introduction of flow-stabilizing components such as the Dip Plate and Center Shaft of the Downstream Defender®, transitory eddies are replaced by stable epicyclical vortices along the perimeter of the chamber (Fig.12b). The submerged tangential inlet further reduces turbulence by preventing cascading influent flow from disrupting the water surface.

The resulting rotational flow path is stable and generates a low headloss, thereby providing a better environment for pollutant settling.

Fig.12 a) A view of the chaotic flow path of a basic vortex separator with no flow-stabilizing components; b) The flow stabilizing components of the Downstream Defender® minimize turbulence over a wide range of flows to increase settling performance and minimize headloss.

The Three-Dimensional Flow Path within the Downstream Defender®

Essential Features of AVSs

Stable Rotational Flow Regime

3D Flow Path

Prevents Pollutant Washout

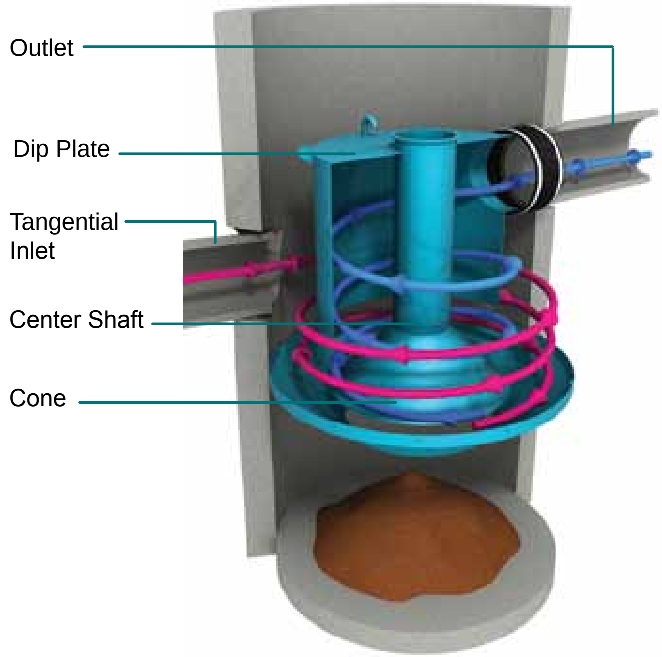


Fig.13 The flow-modifying components of the Downstream Defender® create a long, stable three-dimensional flow path to maximize residence time.

Benefits of a 3D Flow Path

A stable flow regime (Fig.13) reduces turbulence within the separator, thereby:

- Eliminating Short Circuiting
- Maximizing Residence Time
- Reducing Footprint of Separator

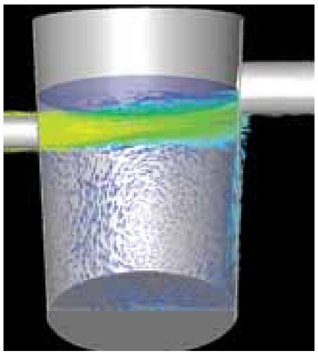
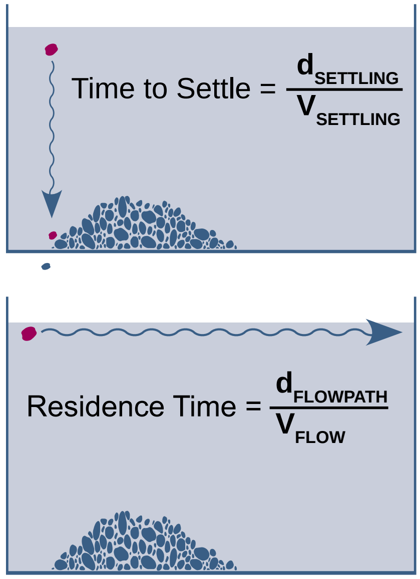


Fig.15 Fluid modeling shows basic separators are prone to short-circuiting (yellow and green fluid vectors).

A particle settles when its residence time within a separator is greater than its time required to settle (Fig. 14). For maximum separator performance, residence time should therefore be as long as possible. Basic gravity and vortex separators are prone to "short circuiting", the phenomenon by which flow passes directly from inlet to outlet without making its way through the entire treatment device (Fig.15).



The flow-modifying components of the Downstream Defender® were designed to eliminate short circuiting by directing flow in a long, spiraling three-dimensional path (Fig.13).

Rotational flow passes down around the dip plate and up around the center shaft cylinder to the outlet. There is no direct linear route from inlet to outlet, therefore short-circuiting is prevented.

The long rotational flow path results in a longer residence time within the device, thereby increasing the time available for pollutants to settle. By the time flow reaches the outlet it is virtually free of floatables and settleable solids.

Fig.14 A particle settles when its residence time within the separator is greater than the time required to settle. Settling time is a function of the distance from the particle to the sump ($d_{SETTLING}$) and settling velocity ($V_{SETTLING}$). Residence time is a function of distance from flow inlet to flow outlet ($d_{FLOWPATH}$) and flow velocity (V_{FLOW}).

Essential Features of AVSs

Stable Rotational Flow Regime

3D Flow Path

Prevents Pollutant Washout

Benefits of Preventing Pollutant Washout

Retaining all captured pollutants:

- Prevents the Re-release of Harmful Stormwater Pollutants into the Environment
- Increases the Net Efficiency of the Device
- Protects Downstream Filtration/Infiltration Stormwater BMPs from Filling Up with Sediment

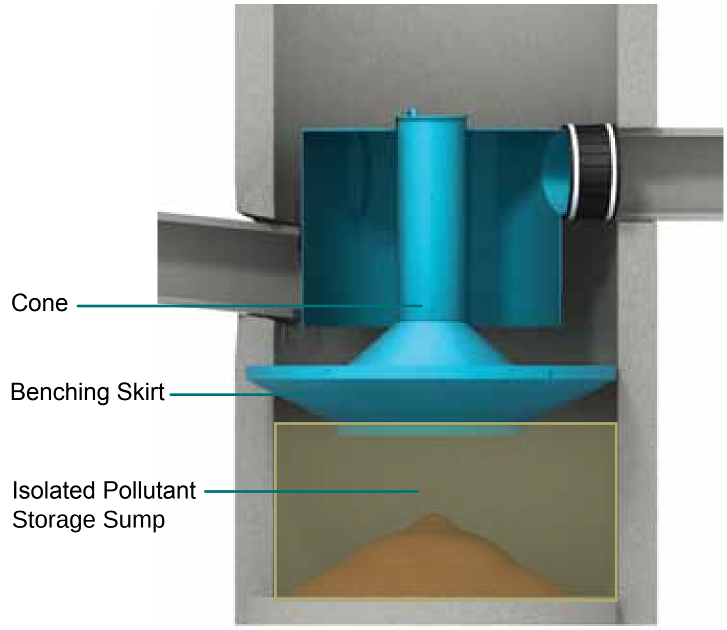


Fig. 16 The washout-preventing components of the Downstream Defender®.

What Is Pollutant Washout?

Pollutant washout is the process during which solids previously captured within the sump of a separator are scoured by active flow, resuspending the sediments into the active flow stream and washing them out of the outlet pipe.

Both gravity separators and basic vortex separators have been shown to wash out. A study by Liverpool John Moores University showed that, under the same peak flow conditions, a gravity separator retained less than 10% of 75-micron sediment and a basic vortex separator retained only 60% of the same material (Phipps et al., 2005). See Fig.17.

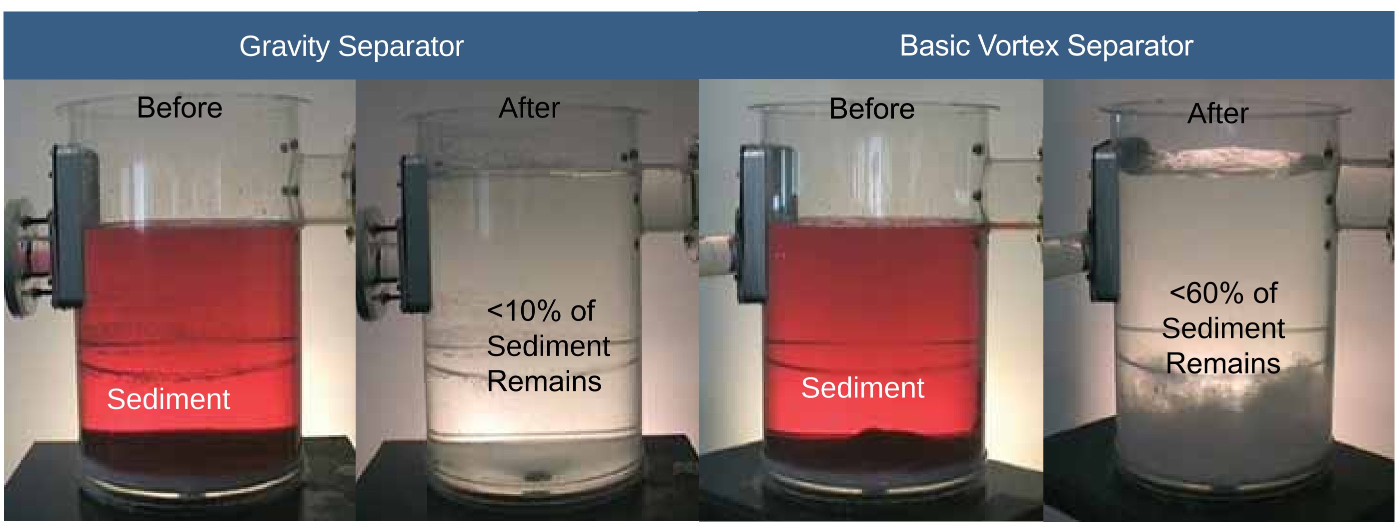


Fig.17 In a 2005 study, 75-micron sediment was pre-loaded into the sumps of a gravity separator and basic vortex separator. After 5 minutes under peak flow conditions, the gravity device (left) lost >90% of the previous captured sediment and the basic vortex separator lost >40% (Phipps et al., 2005).

The same study showed that the Downstream Defender® retained more than 99% of 75-micron material during washout tests, far outperforming the gravity separator and basic vortex separator (Fig.18a, b).

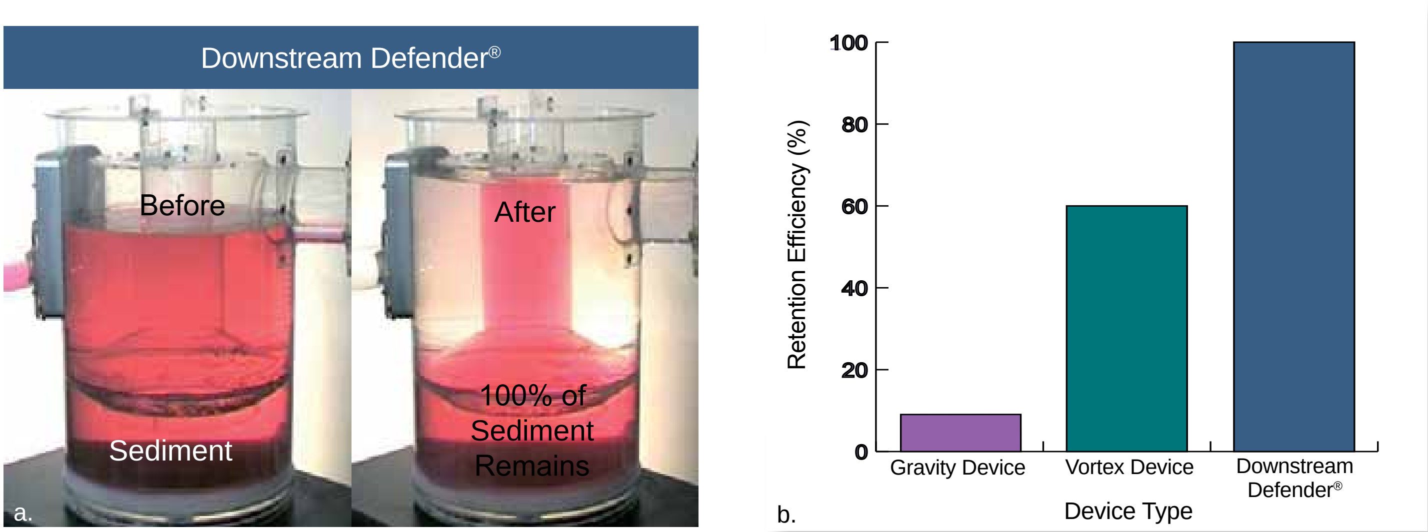


Fig.18 a) The Downstream Defender® retained more than 99% of 75 micron material in the sump after 5 minutes of peak flow conditions; b) Results of comparative washout testing show that the Downstream Defender® retains more sediment than gravity and basic vortex devices (Phipps et al., 2005).

Why Washout Happens

Washout occurs when settled pollutants are exposed to high flow velocities.

Many conventional hydrodynamic separators do not have internal components that protect settled pollutants from the high flow velocities that occur with the peak of a storm.

Flow and particle transport modeling reveals what is happening in a conventional gravity separator during the peak of an event (Fig.19). The flow scheme is chaotic and turbulent. The flow paths penetrate the sump of the separator with relative high velocity. The sediment pathline model shows the impact that the turbulent flow scheme is having on sediment settled in the sump. The sediment path lines show that the material is scoured from the sump, resuspended within the active treatment chamber and ultimately washed out of the device (Phipps et al., 2005).

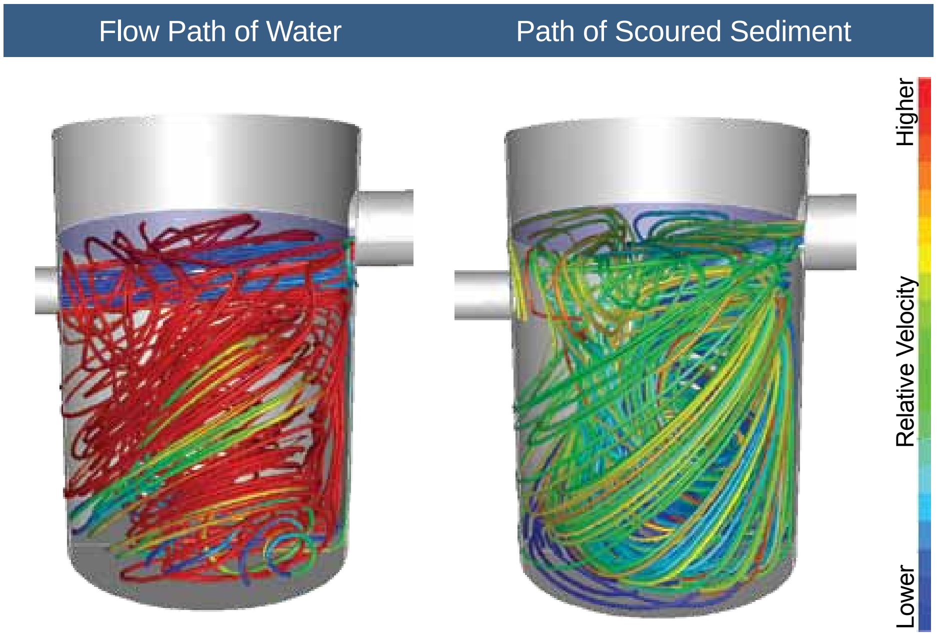


Fig.19 During the peak of a storm event, the flow scheme within a gravity separator is turbulent. The turbulent, high-velocity flow scheme scours settled sediment from the sump, re-suspending it within the separator and ultimately washing it out of the device.

How the Downstream Defender® Prevents Washout

To protect sediment from washout, a separator must first convey pollutants to a pollutant storage zone then protect the pollutant storage zone from high flow velocities during peak flows. Many devices accomplish only one of these two vital functions.

The Downstream Defender® Prevents Washout by:

- Effectively Conveying Solids to a Sediment Storage Zone
- Protecting the Sediment Storage Zone from High Flow Velocities that Cause Scour

To protect sediment from washout, Advanced Vortex Separators such as the Downstream Defender® incorporate features that protect settled sediment from high flow velocities.

Conveying Pollutants to the Storage Zone

For a separator to effectively retain captured pollutants, it must first effectively convey settling pollutants into its designated sediment storage zone.

Some basic separators feature a flat "shelf" that serves to separate the active treatment chamber from the sediment storage zone. Although the intended purpose is to prevent settled pollutants from washing out of the device, the actual result has the opposite effect. The Phipps et al., (2005) study captured video imaging of sediment caught on the flat shelf washing out of a vortex separator at moderate flows (Fig.20a).

The sloped Benching Skirt of the Downstream Defender® conveys settling solids down into the sediment storage sump. The Cone, situated over the opening within the Benching Skirt, prevents the active vortex flow regime from penetrating the sump.

The Downstream Defender® was designed to prevent pollutants from accumulating on the Benching Skirt. The Benching Skirt is sloped beyond the "critical angle of repose", the steepest angle at which a granular material will settle instead of slide (Fig.20b). Pollutants are effectively conveyed to the sump where they are protected from washout.

Post-installation photos taken from the outlet pipe of the High Energy Vortex Separator from Fig.20a show a trail of sediment exiting the device after being scoured from the sump during a preceding storm event (Fig.21a).

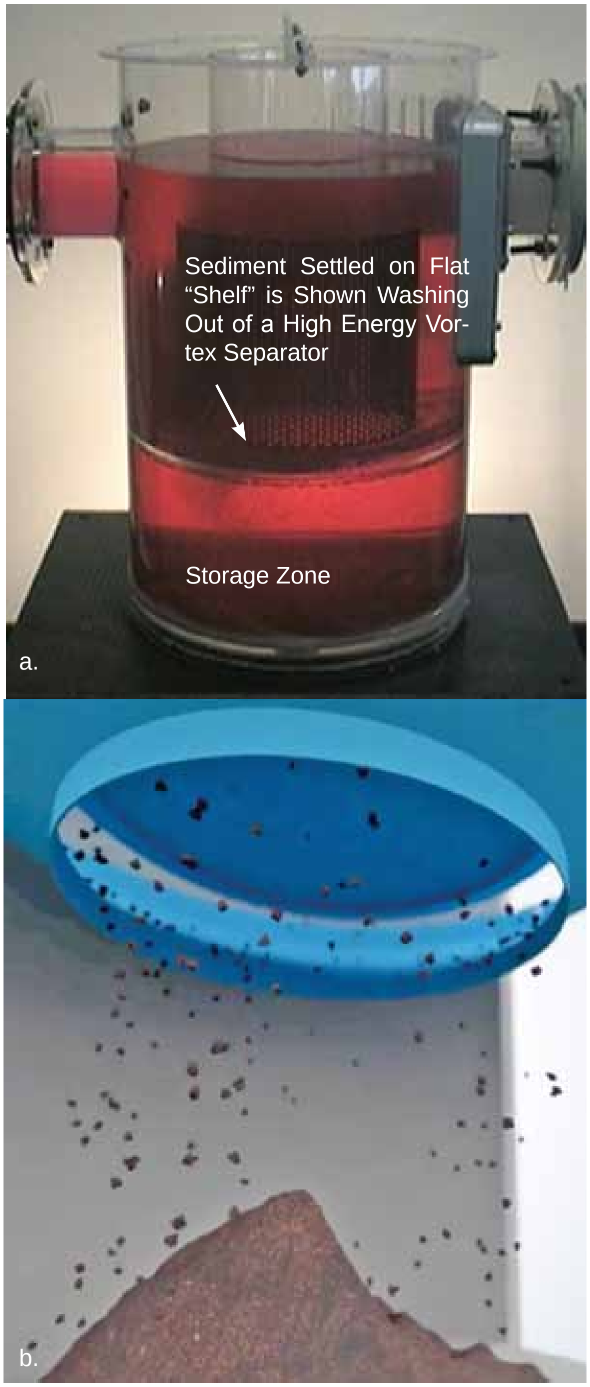


Fig.20 a) Sediment caught on the flat shelf of a high energy vortex separator is shown washing out at moderate flows during the 2005 experiment conducted by Liverpool John Moores University; b) The Benching Skirt of the Downstream Defender® is sloped beyond the "angle of repose" to prevent sediment from settling on it.

Conversely, the outlet pipe of a Downstream Defender® installed for more than two years is free from sediment deposition (Fig.21b).

The occurence of sediment in the High Energy Vortex Separator outlet pipe and the lack of sediment in the outlet pipe of the Downstream Defender® are in line with the findings of the 2005 Liverpool John Moores University study.

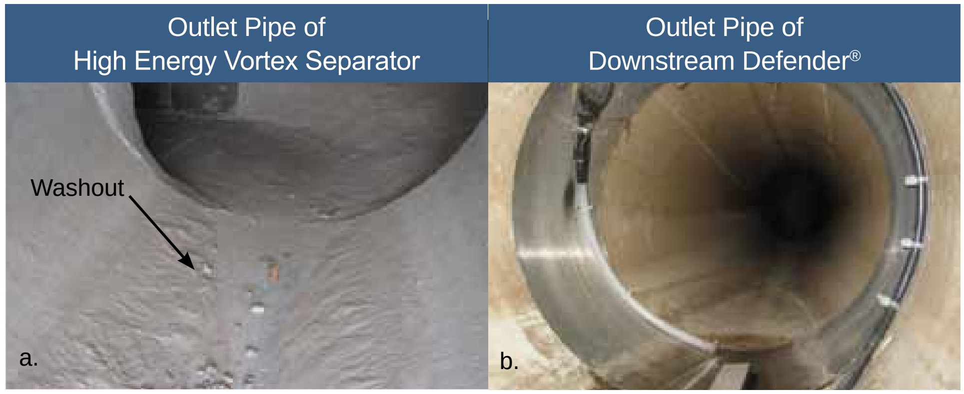


Fig.21 a) A field photo taken from the outlet pipe looking into a High Energy Vortex Separator shows a trail of sediment washing out of the device, whereas b) a field photo taken from the Downstream Defender® shows that the outlet pipe is free from sediment deposition.

Protecting Sediment Storage from High Scour Velocities

The Benching Skirt and Cone are the key components used to protect the pollutant storage sump of the Downstream Defender® from washout.

The Benching Skirt forms a physical barrier between the treatment chamber and pollutant storage sump. The Cone, situated over the opening of the Benching Skirt, prevents the vortex flow regime from penetrating the sump (Fig.22a) and resuspending captured sediment (Fig.22b).

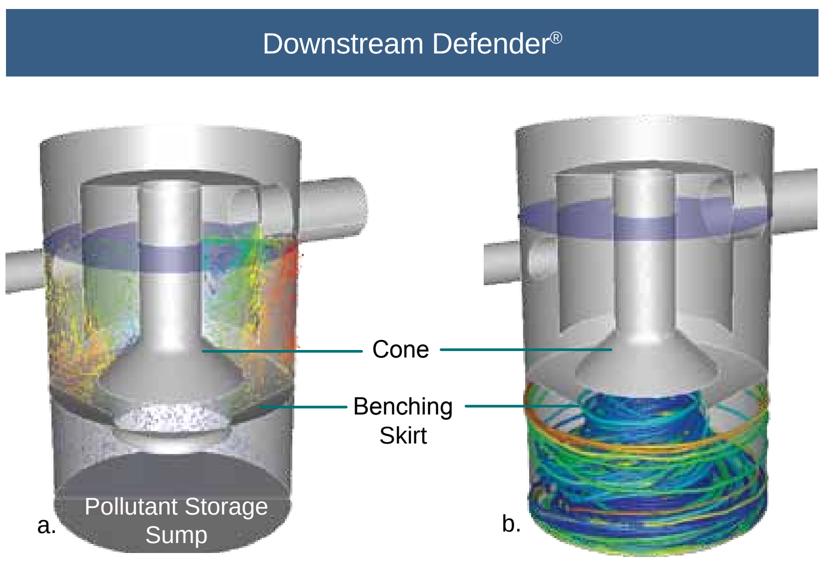


Fig.22 a) CFD Modeling of velocity vectors within a Downstream Defender® show quiescent conditions within the sump, as indicated by the low density of dark blue velocity vectors; b) Particle transport modeling shows that although sediment in the base moves around slowly, it does not leave the sump.

See the Downstream Defender®
Washout Test Video

www.hydro-int.com/us/products/downstream-defender

Further Information

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Introductory Video

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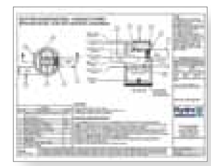
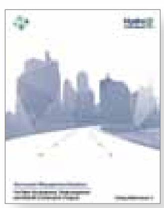


GA Drawings

Product Catalogs



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