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# Analysis of Hydrodynamic Separators for Combined Sewer Overflows and Stromwater Runoff Control

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**Abstract**

Appropriate removal of pollutants from combined sewer overflows(CSOs) and stormwater runoff is of primary concern to watershed managers trying to meet water quality standards even under a wet weather condition. Harmful substances associated with particles besides TSS and BOD are subjected to removal prior to discharge into the natural waters. Effectiveness of five major hydrodynamic separation technologies, Vortechs, Downstream Defender including Storm King for CSOs control, CDS, Stormceptor, and IHS, were evaluated in this study. There is not sufficient information for accurate evaluation of the removal efficiency for the pollutants from the stormwater runoff and CSOs. Based upon limited engineering data, however, all technologies were found to be effective in separation of heavy particles and floating solids. Technologies utilizing screens seem to have advantage in the treatment capacity than the other technologies relied fully on hydrodynamic behavior. The IHS system seems to have a strong potential in application for control of CSOs because of unique hydrodynamic behavior as well as a flexibility in opening size of the screens. Size of the particulate matter in the CSOs and stormwater runoff is found to be the most important parameter in selection of the type of the hydrodynamic separators. There exists an upper limit in the solids removal efficiency of a hydrodynamic separator, which is strongly dependent upon the particle size distribution of the CSOs and stormwater runoff.

**Key words:** CSOs, IHS, particle, screen, settling, stormwater, vortex

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## INTRODUCTION

A combined sewer which carries both wastewater and stormwater discharges a great deal of pollutants into the receiving water without any form of treatment. Vladimir et al. (1994) claimed that urban non-point source including CSOs released 760 times more load of lead than point source. **Table 1** shows the approximate concentration ranges of point and non-point urban source related with stormwater runoff. In addition to the traditional pollutants reported in the **Table 1** stormwater runoff contains various priority pollutants and harmful substances such as oils, polyaromatic hydrocarbons (PAHs), PCBs and toxic heavy metals including lead (Myers et al., 1985).

It is important to investigate on the solid classification and the particle size distribution of the CSOs and stormwater runoff. However, most gross pollutants cannot properly sampled or are overlooked when evaluating the impact of the CSOs and stormwater runoff on receiving waters. Gross solids which is one of the most important parameter in stormwater runoff have been defined by Jefferies and Ashley (1994) as sewer solids that are >6mm in any direction. While, Australia has adopted a criterion defining the size of the gross solid as larger than 5mm.

Standard Methods defines "Total Solids" (TS) as the material residue left after evaporation of a sample and drying in an oven at a defined temperature. Total solids includes "Total Suspend Solids (TSS), the portion of totals solids retained by filter, and "Total Dissolved Solids" (TDS), the portion that passes through the pores of a glass fiber filter (2.0$\mu$m or smaller). However, the method for TS and TSS analysis allows for the exclusion of large floating particles or submerged agglomerates of non-homogeneous materials. Therefore, the size of particles in stormwater runoff is more important than TSS itself because always the higher concentration of pollutants is composed of finer particles (< 100$\mu$m) while the mass of pollutants is frequently associated with the particles larger than100$\mu$m.

Sartor (1972) investigated street surface runoff and found 6% of total solids was less than 43$\mu$m, 37% ranged from 43 to 246$\mu$m, and 57% was grater than 246$\mu$m. Shaheen (1975) in similar studies of material deposited on highways found the size distribution, about 10% of the particles to be less than 75$\mu$m, 32% between 75 and 250$\mu$m, 24% between 250 and 420$\mu$m, 19% between 420 and 850$\mu$m, and the rest between 850 and 3,350$\mu$m. In another study, Sansalone (1997) investigated rainfall runoff from a freeway and reported a size distribution showing 10% of the particles less than 100$\mu$m, 25% between 100 and 400$\mu$m, 15% between 400 and 600$\mu$m, 20% between 600 and 1,000$\mu$m, and 30% between 1,000 and 10,000 $\mu$m. Much greater particles are dominant in the urban or highway runoff than the municipal wastewater in the form of floating or suspended solids.

## CHARACTERISTICS OF HYDRODYNAMIC SEPARATORS

USEPA(1999a) has defined that a stormwater best management practice (BMP) is "a technique, measure, or structural control that is used for a given set of conditions to manage the quantity and improve the quality of storm

**Table 1.** Comparison of the strength of CSOs with other sources

| Type of Wastewater | BOD5 (mg/l) | SS (mg/l) | TN (mg/l) | TP (mg/l) | Lead (mg/l) | Total Coliforms[1] |
|---|---|---|---|---|---|---|
| CSOs | 60-200 | 100-1100 | 3-24 | 1-11 | (0.4) | 105-107 |
| Urban stormwater | 10-250 | 3-11,000 | 3-10 | 0.2-1.7 | 0.2-1.7 | 105-108 |
| runoff(typical)[2] | (30) | (650) | | (0.6) | (0.6) | |
| Typical sewage | 160 | 235 | 35 | 10 | NA[3] | 107-109 |
| Roof runoff | 3-8 | 12-216 | 0.5-4 | NA | 0.005-0.03 | 102 |

Note: 1. unit = MPN/100ml, 2. ( ) = mean, 3. NA = not available.

water runoff in the most cost-effective manner." BMPs can be either engineered and constructed systems ("structural BMPs") that improve the quality and/or control the quantity of runoff such as detention ponds and constructed wetlands, or institutional, education, or pollution prevention practices designed to limit the generation of storm water runoff or reduce the amounts of pollutants contained in the runoff ("non-structural BMPs").

Hydrodynamic separators are not intended for retention or detention but flow-through structures with settling or separation unit to remove variety of solids from stormwater runoff. No outside power source is generally required, because the energy of the flowing water allows particles to be efficiently separated. Depending on the type of the unit, separation may be accomplished by means of swirl action or direct/indirect filtration. They are most effective where the materials to be removed from stormwater runoff are heavy particles which are settleable or floatable rather than solids with poor settleability or dissolved pollutants (US EPA 1999b). The need for hydrodynamic separators is growing as a results of decreasing land availability for the installation of stormwater retention facilities which is the most effective means among the BMPs. This study discusses and evaluates effectiveness of four hydrodynamic separators available in the world market and a newly developed hydrodynamic separator in Korea in order to provide a better understanding of the processes involved and to aid in decision making on selection of a unit for control of CSOs and stormwater runoff.

**Vortechs**

The Vortechs™ stormwater treatment system as shown in **Fig. 1**, developed by Vortechnics™ of Portland, Maine, has been available since 1988. Vortechs remove floating pollutants and settleable solids from CSOs and stormwater runoff. The system consists of a grit chamber, an oil chamber, and a flow control chamber.

The main function of each chamber can be described as follows:

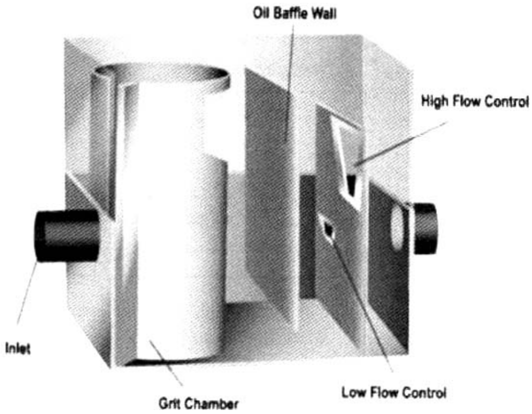



**Fig. 1.** Vortechs™ system.

- Grit chamber - The swirling motion is induced by the tangential inlet flow and created by the difference of water levels. The vortex motion leads particles to be in the swirling flow path and to be captured in the grit chamber.
- Oil chamber with baffle wall - The center barrier traps floatables including oil.
- Flow control chamber - This device helps keep pollutants trapped by reducing the forces that encourage resuspension and washout. This chamber also helps to eliminate turbulence within the system.

Vortechnics manufactures 9 standard-sized units which are ranged from 9 feet by 3 feet to 18 feet by 12 feet. Vortechs systems are able to treat runoff flows ranging from 1.6 to 25 cfs. For Vortechs systems without bypass, sizing criteria is based on grit chamber surface area for 100 gpm of peak design storm flow rate. Weir or high flow control is sized to pass the peak system capacity minus the peak orifice flow when the water surface elevation is at the top of the weir.

If Vortechs system is operated above 100 gpm/ft$^2$ (2.44 m$^3$/m$^2$/hr), captured pollutants may be lost and recommended hydraulic loading becomes 24 gpm/ft$^2$ grit chamber area. **Fig. 2** shows the results of full-scale testing with Vortechs Model 2000. The 150$\mu$m curve demonstrates the results of tests using particles passing through a 100-mesh sieve (#100) and being retained on a #150 sieve. The 50$\mu$m curve demonstrates the results of

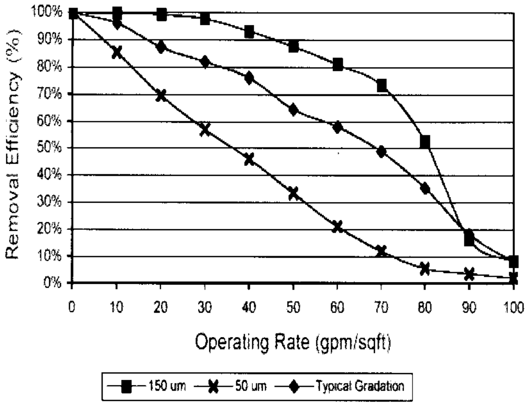



**Fig. 2.** Removal efficiencies for selected particle gradations.

tests using particles that pass through a #200 and are retained on a #400 sieve. Typical Gradation curve has been obtained with the make-up sample in typical urban runoff (USEPA, 1999b; www.vortechnics.com). Reduced removal efficiency for small particles or at high loading is a common problem for the hydrodynamic separators.

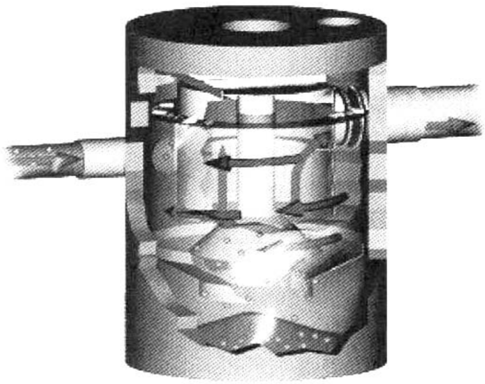
### Downstream Defender

The Downstream Defender developed and manufactured by H.I.L. Technology, Inc. is designed to capture settleable solids, floatables, and oil and grease. The unit as shown in **Fig. 3a** is a modified standard manhole installed below grade with a tangential inlet pipe. Two ports at ground level provide access for inspection and clean-out of stored floatable and sediment. The internal components consist of two concentric hollow cylinders(the dip plate and center shaft), an inverted cone(the center cone), a benching skirt and floatables lid. H.I.L. Technology, Inc. also developed a CSOs treatment unit named Storm King as shown in **Fig. 3b**. The Storm King (see (b) of **Fig. 3**) adopted the conical screen and the siphon facility on top of Downstream Defender. The operation of the siphon is a principal component in the effectiveness of both the self-cleansing and self-activating features of the screen.

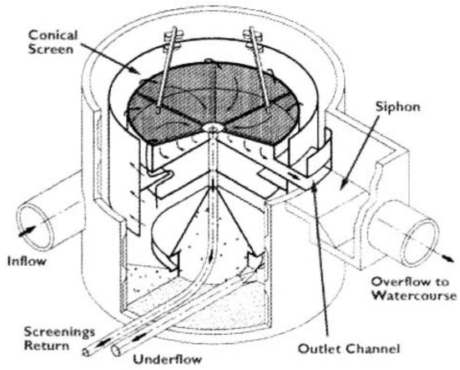
The Downstream Defender is available for pre-designed standard manhole size, typically 4, 6, 8 and 10 feet in diameter. In a special case, diameter of the unit is designed up to 40 feet. Flow of these units is rated at 0.75, 3.0, 7.0 and 13.0 cfs. Capacity flowrate is based on keeping with a standard inlet pipe. Higher flow rates are possible if lower removal efficiencies and higher head losses are acceptable. Head losses can be minimized by increasing the inlet pipe diameter up to the standard outlet pipe diameter. Standard specifications are available for typical design criteria of 90% removal of all particles grater than 150$\mu$m with the specific gravity of 2.65 at design flow (USEPA, 1999b; www.hydrointernational.biz).

### Continuous Deflective Separation (CDS)

CDS technology developed in Australia allows screening of solids from liquid at high flowrates as shown



a. stormwater control unit




b. CSOs control unit

**Fig. 3.** Downstream Defenders of H.I.L. Technology, Inc.

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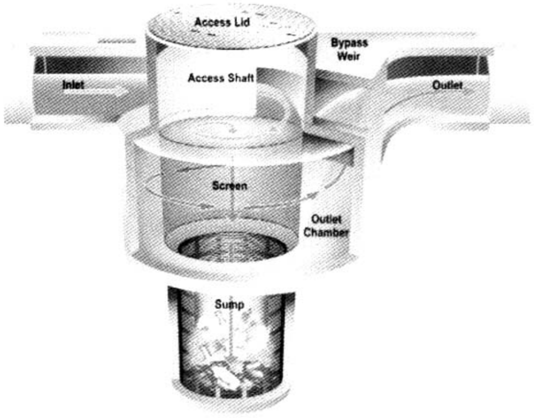


**Fig. 4.** Schematic view of CDS separator showing basic components.

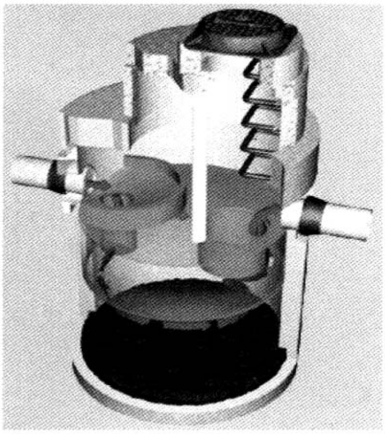

**Fig. 5.** Single in-line Stormceptor.

in **Fig. 4**. It is claimed that the screen always remains clean and does not affect the separation efficiency as the solids are removed from the flow.

CDS separator consists of an approximately cylindrical tank made of concrete, stainless steel or fibreglass with inlet and outlet channels that lead the water smoothly to and from the unit. A cylindrical screen is located inside the tank and the influent is introduced tangentially to the inside of the screen, forming a continuously rotating body of water that provides a washing effect across the face of the screen. The screen openings of CDS are of 3 sizes depending upon the application. Stormwater screens usually used have either 2.4mm or 4.7mm longway opening, while 1.2mm screen opening is found to be most effective for CSOs or SSOs control (Lee and Jago, 2002). The region inside the screen is known as the separation zone and trapped solids either floating on the top of the fluid or settling into a collection sump may be removed by a pump or other means.

The capacity of CDS units varies from 3 to 300 cfs. But the flow rate of CDS is decreased by about 30% when CSOs or SSOs are to be treated. In laboratory results testing with sand, the removal efficiencies were good for particles greater than 425$\mu$m, showing capture rate near 100%. For particles less than 300$\mu$m, the removal efficiency of the particles dramatically decreased. Overall mass capture rate was 84% for 1.2mm screen opening with a detention time of 43 seconds (Schwarz and Wells, 1999). CDS technology is suitable for gross pollutant removal.

### Stormceptor

Stormceptor developed by CSR Hydro Conduit based in Canada is shown in **Fig. 5**. There are four type of products, in-line, inlet, series, and submerged Stormceptor. The in-line Stormceptor is most commonly installed for stormwater control. Stormceptor is designed to trap and retain a variety of non-point source pollutants associated with particles using a by-pass chamber and a treatment chamber. Stormceptor units are available in prefabricated sizes up to 12 ft in diameter by 6 to 8 ft deep. The manufacturer reports that Stormceptor is capable of removing 50 to 80% of the total sediment load when used properly. It has a merit in simple structure and simplicity in operation.

### Innovative Hydrodynamic Separation (IHS)

IHS system for control of CSOs and stormwater runoff developed in Korea is a hybrid form of vortex and screen type separator. Schematic diagram of IHS unit is shown in **Fig. 6**. As the influent through inlet pipe introduced tangentially to the guide vane near the bottom of screen, centrifugal rotation by contacting with the guide vane

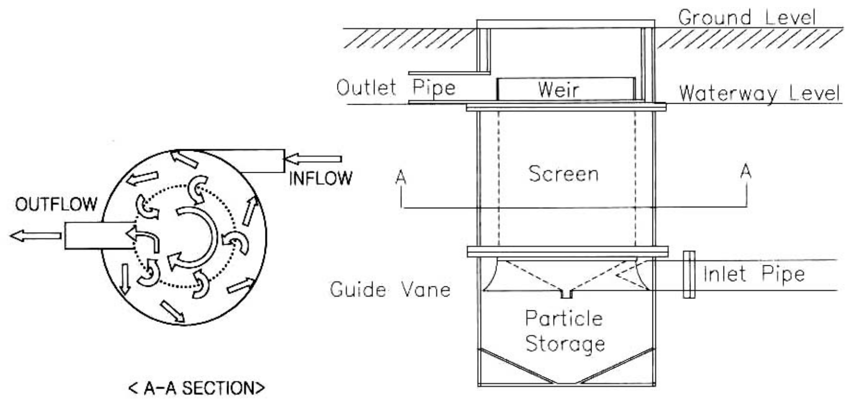


**Fig. 6.** Schematic view of IHS unit.

occurs in annular zone between the main body and the screen. The particles in water are collided with the outer wall by the centrifugal action of the rotational upward flow. Fraction of the water passes trough the openings of thel screen with diamond shaped apertures. As the water flows upward and inward through the screen, centrifugal rotating velocities near the wall decrease sharply and the slow rotational flow inside the screen in opposite direction becomes dominant. The inner zone of the screen is calm and stable and quiescent settling can take place, although there is a very fast centrifugal rotating velocity at the annular zone near the bottom inlet. Clarified water is collected from the inner zone at the top across the circular weir to the outlet pipe.

Laboratory tests have been carried out to determine the flow pattern and the solids removal efficiency. An experimental IHS unit consisting of 50cm diameter cylindrical tank, 30cm diameter and 40cm high screen, and 5cm diameter inlet pipe with a hydraulic retention time of 1.7min was used for performance evaluation. The screen applied has 2.5mm long way openings. Three dimensional velocity distribution clearly demonstrates flow pattern of the system. High rotational flow near the wall at the bottom inlet and much lower velocity of opposite direction at inner zone provide an ideal condition for collision and sedimentation of the particles. Glass beads with the size ranging from 45$\mu$m to 2,380$\mu$m and the specific gravity of 2.52 were utilized as input

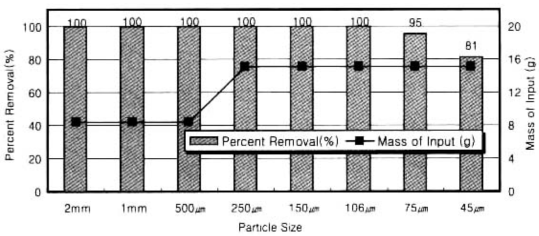


**Fig. 7.** Solids removal efficiency of IHS system.

solids. Experimental results of solids removal for IHS system are shown in **Fig. 7**. Removal efficiency was excellent for the particles greater than 106$\mu$m, displaying capture rate of 100%. The minimum particles size used in the test, 45$\mu$m, were satisfactorily removed by 81%.

## EVALUATION OF HYDRODYNAMIC SEPARATORS

Performance evaluation of the hydrodynamic separators under Identical or similar conditions such as installation location, rainfall events, loading rate, and frequency of cleaning is essential for reliable results. Unfortunately, very limited information under widely varied conditions is currently available for the separators examined. While some data suggest excellent or poor removal efficiency, they often depend on site-specific conditions as well as other contributing factors.

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**Table 2.** Cost and performance comparison for hydrodynamic separators

| Product | Performance Data (% removal/capturable size) | | Note of Performance Data | Flow Capacities | Costs, $ | |
|---|---|---|---|---|---|---|
| | TSS (%) | Particle size (μm)[1)] | 1) Removal size | cfs | Purchase | O&M/yr |
| Vortechs | 80[2)], 84[3)] | NA | 2) Lab test at 24 gpm/ft$^2$<br>3) 7storm events. EMCc base | 1.6(0.4)[a]<br>-<br>25(6.2)[a] | 10,500<br>-<br>40,000 | 400+ |
| Downstream Defender | NA | 200μm for 90% removal | NA | 3.0(0.8)[a]<br>-<br>25(6.2)[a] | 10,300<br>-<br>26000 | 500+ |
| CDS | 84[4)], 70[5)] | 425μm for near 100% | 4) Lab test at 125 gpm<br>5) 4700μm aperture not effective for TSS<75mg/l | 1.1<br>-<br>300 | 9,600<br>-<br>332,500 | 400+<br>-<br>1,450 |
| Stormceptor | 80[6)], 26[7)], 93[8)], 53[9)] | NA | 6) 4 storm events. EMC base<br>7) 45storm events. EMC base<br>8) 3 storm events. EMC base | 0.17<br>-<br>2.47 | 4,500<br>-<br>34,570 | 500<br>-<br>1000 |
| IHS | NA | 106μm[10)] for near 100% | 10) Lab test at detention time 1.0min | NA | NA | NA |

Source: Sacramento Stromwater Management Program,1999 except for IHS.
a. Capacities in ( ) indicate recommended design capacity for 80 percent TSS removal
b. NA indicate "Not Available"
c. EMC indicate "Event Mean Concentration"
d. The unit is under developing.

program(1999) selected proprietary devices and evaluated information supplied by the manufacturers of units. Cost data were developed only for the purpose of general comparison and were not prepared for intended use as a basis for determining acceptance or rejection of the products. Operation and maintenance costs per year (O&M/yr) must be widely different according to the conditions of site, climate, and frequency of clean-up of the units. Besides above conditions, site constraints, availability of suitable land, appropriate soil depth and stable soil to support the unit structurally, may also limit the applicability of the hydrodynamic separators. **Table 2** shows the evaluation of the hydrodynamic separators provided by Sacramento stormwater management program(1999) along with limited data on IHS.

All hydrodynamic separators examined are sufficiently effective where the separation of heavy particulate or floatable is required. Main separation mechanisms of five technologies commonly include screening, gravity settling, vortex and centrifugal motion. Solids removal of three technologies, Vortechs, Downstream Defender including Storm King, and Stormceptor, are generally based on the vortex separation. While, CDS and IHS unit utilize screens for additional solids removal.The CDS units mainly use a screening function in order to trap completely gross solids, while the IHS system is based not only upon screening but also upon centrifugal and setting motion. AS a result, the IHS system is capable of removing solids of various ranges, from gross solids to fine particles with a proper selection of the opening size. Higher solids removal efficiency is possible with higher costs of operation and maintenance for the hydrodynamic units such as Storm King and IHS system. Although there is a reduction in the removal efficiency, ease of operation and maintenance must be an important advantage for the separators relied only upon hydrodynamic behavior such as Vortechs and Stormceptor. The CDS units show lower cost per cfs treated but also appear to have lower efficiencies in particles removal than the other technologies. The IHS system seems to be most promising in terms of finer solids removal efficiency because of flexibility in size of the screen openings. However, solids of poor settling velocity and dissolved solids are not effectively removed by any hydrodynamic separator. There must be an upper limit in the pollutants removal efficiency of the hydrodynamic separators. Innovative design of the separator or post-treatment of the effluent might be necessary, if an efficiency over the upper limit is required.

## SUMMARY AND CONCLUSIONS

TSS dose not consistently correlate to the characteristics of CSOs and stormwater runoff because of exclusion of floating solids as well as fine colloids. Particulate size is an important parameter to evaluate effectiveness of the hydrodynamic separation technologies. Although there was not sufficient information in the aspects of technology and economy, an attempt was made to evaluate effectiveness of five well known hydrodynamic separation technologies in order to obtain and perform BMPs for successful watershed management. All examined separators were highly effective in separation of heavy particles and floating solids, however, removal efficiency of the solids of poor settling velocity was significantly reduced. There is an upper limit in the solids removal efficiency of a hydrodynamic separator, which is strongly dependent upon the particle size distribution of the CSOs and stormwater runoff. The IHS system seems to have a strong potential especially in application for control of CSOs.

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