# Storm King® as a contact vessel for disinfection

Technical Bulletin



Turning Water Around…®

## Introduction

Storm King® has long been used as a vessel for preventing solids, grit, and screenings from being discharged at combined sewer overflows (CSOs). If disinfection of the discharge is also required, the norm has been to provide separate tanks for disinfection. Trials conducted at Columbus and Saco have shown that because of the flow characteristics of the Storm King®, both solids removal and disinfection can be achieved in the same vessel. This bulletin outlines the theory of how this is achieved; along with practical examples from active full-scale sites, and cites where independent studies have been undertaken on this application, together with what was observed.

## Disinfection Theory

The elimination of harmful bacteria by disinfection has been practiced for decades. The rate of die-off of micro-organisms can be described as an empirical first order kinetic equation commonly referred to as "Chick's Law" (USEPA 1986).

$$\frac{-dN}{dt} = kN$$

Where N is the number of surviving organisms per unit volume at any given time, and k is the organism die-off constant. (Chick 1908)

It is recognised that many factors can cause deviations from the model such as changes in disinfectant concentration over time, and varying resistances of individual micro-organisms. This work was then built on experimentally by Watson to show "a clear definite logarithmic relationship between concentration of disinfectant and mean reaction velocity" (Watson 1908).

Disinfection performance is often measured through changes in concentration of indicator micro-organisms such as total and faecal coliforms over time. The Collins model predicts the reduction in bacterial concentrations as a function of chlorine residual concentrations and system contact time (USEPA 1999).

## The Collins Model

The Collins model of disinfection is built on the work by Chick-Watson (USPEA 1986) on reduction in bacteria concentration as a function of chlorine residual concentrations and system contact time in accordance with the following equation:

$$Y_t = Y_0 (1+0.23CT)^{-3}$$

$Y_t$ = Bacterial concentration after time T (MPN/100ml)

$Y_0$ = Original bacterial concentration (MPN/100ml)

C = Chlorine residual concentration after time T (mg/l)

T = Contact time (min)

The Collins model is widely quoted and accepted in many texts such as Metcalf and Eddy (Metcalf and Eddy 2004) and USEPA (USEPA 1999) as a reasonable model of the effectiveness of the disinfection, with the proviso that initial mixing intensity, CSO water quality, flow characteristic, and disinfectant effectiveness are also considered.

## Reactor Theory

Disinfection ideally occurs in a Plug Flow Reactor (PFR), whereby all of the flow entering the reactor leaves the reactor after the same period of time. This allows the disinfectant the longest possible contact time with the flow. This ideal reactor does not exist, the closest real world approximation of this are serpentine tank type reactors often used for municipal water and wastewater disinfection. The opposite extreme is the Complete Stirred Tank Reactor (CSTR), whereby the flow entering the tank is immediately distributed evenly throughout the reactor; a real world example to this would be a flash mixing tank or “race track” activated sludge plant. In this case some of the flow entering the reactor leaves immediately, whilst some stays in the reactor forever.

A number of CSTR tanks in series can approximate a plug flow reactor, the higher the number of CSTR the closer the approximation, (Perry 1997).

Using the equation

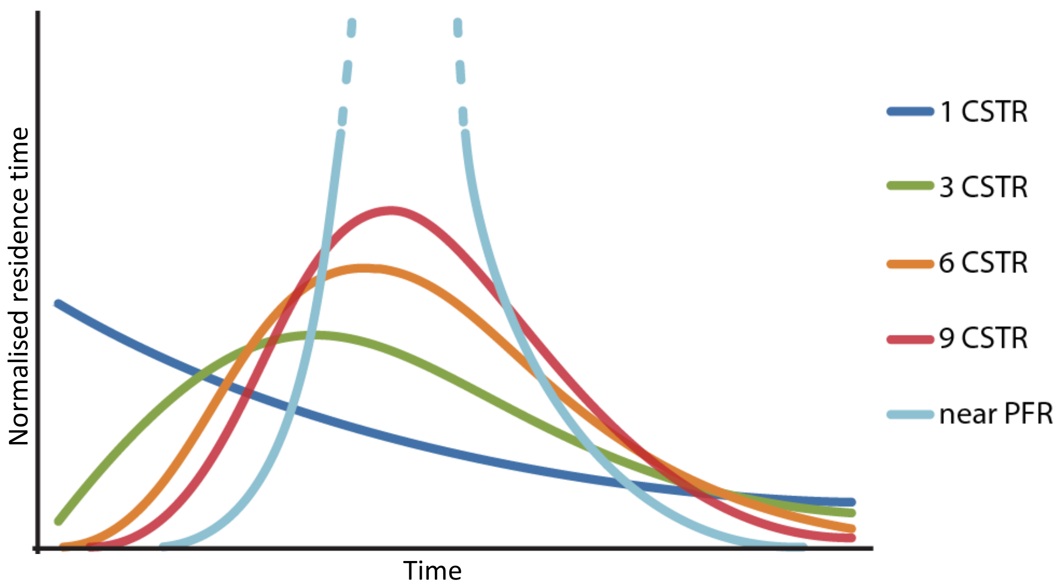
$$E(t_r) = \frac{n^n}{(n-1)!} t_r^{n-1} \exp(-nt_r)$$

$E(t_r)$ is the Normalised residence time distribution

n is the number of ideal mixed tanks in series

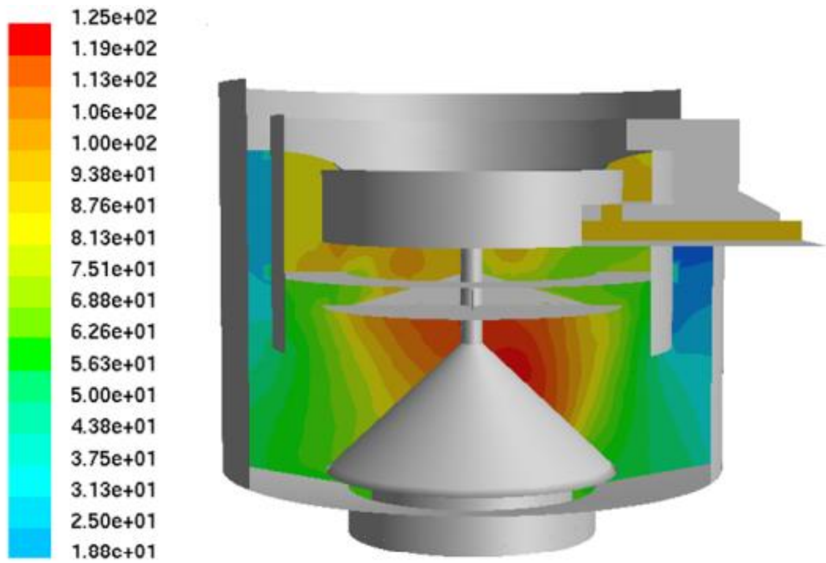
$t_r$ is the time divided by the mean residence time

Residence Time Distribution Characteristics




## Storm King® Reactor Kinetics

Hydro International have undertaken a number of studies of the Residence Time Distribution (RTD) characteristics of the Storm King® using CFD modelling, and have also engaged independent experts in the field to estimate the RTD characteristic of the Storm King® both mathematically and experimentally. (Egarr 2005)



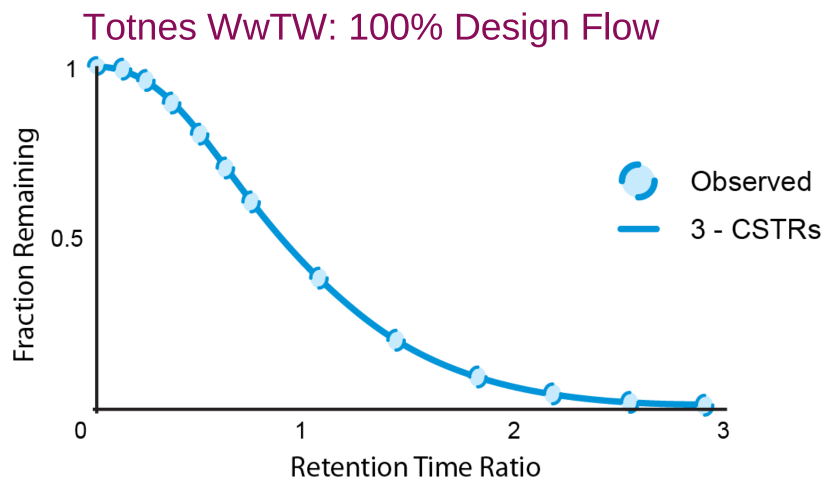

Contours of mean residence time

The Storm King® can be approximated to 3 CSTR tank reactors in series. Using the equation below, the fractional flow leaving in discrete periods of retention time (as a ratio to the mean hydraulic retention time) can be calculated.

| Fractional Time as a percentage of the mean hydraulic residence time | Fraction flow leaving the system during time period |
|---|---|
| 10% | 1.00% |
| 20% | 2.96% |
| 30% | 4.94% |
| 40% | 6.51% |
| 50% | 7.53% |
| 60% | 8.03% |
| 70% | 8.10% |
| 80% | 7.84% |
| 90% | 7.35% |
| 100% | 6.72% |
| 110% | 6.02% |
| 120% | 5.31% |
| 130% | 4.62% |
| 140% | 3.97% |
| 150% | 3.37% |
| 160% | 2.84% |
| 170% | 2.38% |
| 180% | 1.98% |
| 190% | 1.63% |
| 200% | 1.34% |

Based on $E(t_r) = \frac{9}{4} t_r^2 \exp(-3t_r)$ (Perry 1997)

This relationship was also confirmed experimentally at the Totnes Wastewater Treatment Plant in the south west region of the UK, where the dye tracer test results showed remarkable correlation.



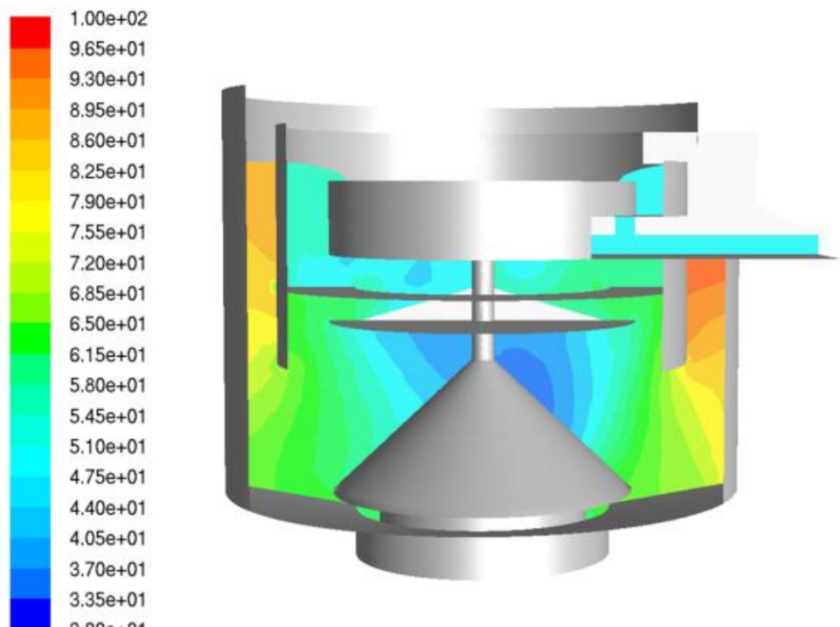

By combining these models it is possible to develop a disinfection model for the Storm King®. The residence time distribution model is divided into 20 identical time segments spanning up to twice the mean hydraulic detention time. The Collins model is then applied to the fractional microbial load in that time segment, with the resultant bacterial level from each segment summated to produce an overall survival level.

$$Y_t = Y_{0.1}(1+0.23CT_{0.1})^{-3} + Y_{0.2}(1+0.23CT_{0.2})^{-3} + Y_{0.3}(1+0.23CT_{0.3})^{-3} + Y_{0.4}(1+0.23CT_{0.4})^{-3} + Y_{0.5}(1+0.23CT_{0.5})^{-3} + Y_{0.6}(1+0.23CT_{0.6})^{-3} + Y_{0.7}(1+0.23CT_{0.7})^{-3} + Y_{0.8}(1+0.23CT_{0.8})^{-3} + Y_{0.9}(1+0.23CT_{0.9})^{-3} + Y_{1.0}(1+0.23CT_{1.0})^{-3} + Y_{1.1}(1+0.23CT_{1.1})^{-3} + Y_{1.2}(1+0.23CT_{1.2})^{-3} + Y_{1.3}(1+0.23CT_{1.3})^{-3} + Y_{1.4}(1+0.23CT_{1.4})^{-3} + Y_{1.5}(1+0.23CT_{1.5})^{-3} + Y_{1.6}(1+0.23CT_{1.6})^{-3} + Y_{1.7}(1+0.23CT_{1.7})^{-3} + Y_{1.8}(1+0.23CT_{1.8})^{-3} + Y_{1.9}(1+0.23CT_{1.9})^{-3} + Y_{2.0}(1+0.23CT_{2.0})^{-3}$$

Where $Y_0 = Y_{0.1} + Y_{0.2} + Y_{0.3} + Y_{0.4} + Y_{0.5} + Y_{0.6} + Y_{0.7} + Y_{0.8} + Y_{0.9} + Y_{1.0} + Y_{1.1} + Y_{1.2} + Y_{1.3} + Y_{1.4} + Y_{1.5} + Y_{1.6} + Y_{1.7} + Y_{1.8} + Y_{1.9} + Y_{2.0}$

Results above twice the mean hydraulic residence time are ignored as it represents a small fraction of the load, and also has the highest kill rate.

CFD modelling has shown that even in very short retention time significant microbial kill occurs (Egarr 2005)




Contours of micro-organism survival, %

# Averages vs. Peaks

Both flow and microbial load vary, therefore designing for an absolute level of microbial survival at all flows and load situations will lead to overdesign of the system. Typically the CSO device will be designed on the basis of peak flows resulting from a 1 in 5, 1 in 30, to 1 in 100 year storm event, therefore in a normal situation the flow experienced by the unit is significantly less than the design flow. This leads to longer contact time being experienced in most storm events than those designed for peak flow conditions.

Equally the microbial load on the system will vary with higher loads experienced infrequently, with high flows unlikely to coincide with high loads due to dilution. The Storm King® model therefore allows designers to understand the risks associated with the retention time and dose selected, allowing the proper balance between capital (unit size) and operating (disinfectant dosing) costs to be appreciated.

**Average F Coli and Average Flow**

| Chlorine Dose (mg/l) | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 15.0 | 16.0 | 17.0 | 18.0 | 19.0 | 20.0 | 21.0 | 22.0 | 23.0 | 24.0 | 25.0 | 26.0 | 27.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22.0 | 16 | 10 | 6 | 4 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 21.0 | 18 | 11 | 7 | 5 | 4 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 20.0 | 21 | 13 | 8 | 6 | 4 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 19.0 | 24 | 15 | 10 | 7 | 5 | 4 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| 18.0 | 28 | 17 | 12 | 8 | 6 | 4 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| 17.0 | 33 | 21 | 14 | 10 | 7 | 5 | 4 | 3 | 3 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| 16.0 | 39 | 25 | 16 | 12 | 8 | 6 | 5 | 4 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 |
| 15.0 | 47 | 30 | 20 | 14 | 10 | 8 | 6 | 5 | 4 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 |
| 14.0 | 58 | 36 | 25 | 17 | 13 | 10 | 7 | 6 | 5 | 4 | 3 | 3 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 13.0 | 71 | 45 | 31 | 22 | 16 | 12 | 9 | 7 | 6 | 5 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| 12.0 | 90 | 58 | 39 | 28 | 21 | 16 | 12 | 10 | 8 | 6 | 5 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 11.0 | 116 | 75 | 51 | 36 | 27 | 21 | 16 | 13 | 10 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 1 |
| 10.0 | 153 | 99 | 68 | 49 | 36 | 28 | 22 | 17 | 14 | 12 | 10 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| 9.0 | 208 | 137 | 95 | 68 | 51 | 39 | 31 | 25 | 20 | 16 | 14 | 12 | 10 | 8 | 7 | 6 | 6 | 5 | 4 | 4 | 3 | 3 | 3 |
| 8.0 | 295 | 195 | 137 | 99 | 75 | 58 | 45 | 36 | 30 | 25 | 21 | 17 | 15 | 13 | 11 | 10 | 8 | 7 | 7 | 6 | 5 | 5 | 4 |
| 7.0 | 439 | 295 | 208 | 153 | 116 | 90 | 71 | 58 | 47 | 39 | 33 | 28 | 24 | 21 | 18 | 16 | 14 | 12 | 11 | 10 | 9 | 8 | 7 |
| 6.0 | 702 | 479 | 343 | 255 | 195 | 153 | 122 | 99 | 82 | 68 | 58 | 49 | 42 | 36 | 32 | 28 | 25 | 22 | 19 | 17 | 16 | 14 | 13 |
| 5.0 | ### | 870 | 635 | 479 | 372 | 295 | 238 | 195 | 162 | 137 | 116 | 99 | 86 | 75 | 65 | 58 | 51 | 45 | 41 | 36 | 33 | 30 | 27 |

Hydraulic Retention Time (min)

**Average F Coli and Max Flow**

| Chlorine Dose (mg/l) | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 15.0 | 16.0 | 17.0 | 18.0 | 19.0 | 20.0 | 21.0 | 22.0 | 23.0 | 24.0 | 25.0 | 26.0 | 27.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22.0 | 90 | 58 | 39 | 28 | 21 | 16 | 12 | 10 | 8 | 6 | 5 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 21.0 | 102 | 65 | 45 | 32 | 23 | 18 | 14 | 11 | 9 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 |
| 20.0 | 116 | 75 | 51 | 36 | 27 | 21 | 16 | 13 | 10 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 2 | 1 |
| 19.0 | 133 | 86 | 59 | 42 | 31 | 24 | 19 | 15 | 12 | 10 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 | 2 |
| 18.0 | 153 | 99 | 68 | 49 | 36 | 28 | 22 | 17 | 14 | 12 | 10 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| 17.0 | 178 | 116 | 80 | 58 | 43 | 33 | 26 | 21 | 17 | 14 | 11 | 10 | 8 | 7 | 6 | 5 | 5 | 4 | 4 | 3 | 3 | 3 | 2 |
| 16.0 | 208 | 137 | 95 | 68 | 51 | 39 | 31 | 25 | 20 | 16 | 14 | 12 | 10 | 8 | 7 | 6 | 6 | 5 | 4 | 4 | 3 | 3 | 3 |
| 15.0 | 247 | 162 | 113 | 82 | 61 | 47 | 37 | 30 | 24 | 20 | 17 | 14 | 12 | 10 | 9 | 8 | 7 | 6 | 5 | 5 | 4 | 4 | 3 |
| 14.0 | 295 | 195 | 137 | 99 | 75 | 58 | 45 | 36 | 30 | 25 | 21 | 17 | 15 | 13 | 11 | 10 | 8 | 7 | 7 | 6 | 5 | 5 | 4 |
| 13.0 | 357 | 238 | 167 | 122 | 92 | 71 | 57 | 45 | 37 | 31 | 26 | 22 | 19 | 16 | 14 | 12 | 11 | 9 | 8 | 7 | 7 | 6 | 5 |
| 12.0 | 439 | 295 | 208 | 153 | 116 | 90 | 71 | 58 | 47 | 39 | 33 | 28 | 24 | 21 | 18 | 16 | 14 | 12 | 11 | 10 | 9 | 8 | 7 |
| 11.0 | 549 | 372 | 265 | 195 | 149 | 116 | 92 | 75 | 61 | 51 | 43 | 36 | 31 | 27 | 23 | 21 | 18 | 16 | 14 | 13 | 11 | 10 | 9 |
| 10.0 | 702 | 479 | 343 | 255 | 195 | 153 | 122 | 99 | 82 | 68 | 58 | 49 | 42 | 36 | 32 | 28 | 25 | 22 | 19 | 17 | 16 | 14 | 13 |
| 9.0 | 921 | 635 | 459 | 343 | 265 | 208 | 167 | 137 | 113 | 95 | 80 | 68 | 59 | 51 | 45 | 39 | 35 | 31 | 27 | 25 | 22 | 20 | 18 |
| 8.0 | ### | 870 | 635 | 479 | 372 | 295 | 238 | 195 | 162 | 137 | 116 | 99 | 86 | 75 | 65 | 58 | 51 | 45 | 41 | 36 | 33 | 30 | 27 |
| 7.0 | ### | ### | 921 | 702 | 549 | 439 | 357 | 295 | 247 | 208 | 178 | 153 | 133 | 116 | 102 | 90 | 80 | 71 | 64 | 58 | 52 | 47 | 43 |
| 6.0 | ### | ### | ### | ### | 870 | 702 | 576 | 479 | 404 | 343 | 295 | 255 | 223 | 195 | 173 | 153 | 137 | 122 | 110 | 99 | 90 | 82 | 75 |
| 5.0 | ### | ### | ### | ### | ### | ### | ### | 870 | 740 | 635 | 549 | 479 | 421 | 372 | 330 | 295 | 265 | 238 | 215 | 195 | 178 | 162 | 149 |

Hydraulic Retention Time (min)

**Max F Coli and Average Flow**

| Chlorine Dose (mg/l) | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 15.0 | 16.0 | 17.0 | 18.0 | 19.0 | 20.0 | 21.0 | 22.0 | 23.0 | 24.0 | 25.0 | 26.0 | 27.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22.0 | 62 | 38 | 25 | 18 | 13 | 9 | 7 | 6 | 4 | 4 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 21.0 | 71 | 44 | 29 | 20 | 15 | 11 | 8 | 7 | 5 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| 20.0 | 82 | 51 | 34 | 23 | 17 | 13 | 10 | 8 | 6 | 5 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 | 1 |
| 19.0 | 95 | 59 | 39 | 27 | 20 | 15 | 11 | 9 | 7 | 6 | 5 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 | 1 |
| 18.0 | 111 | 69 | 46 | 32 | 23 | 18 | 13 | 11 | 8 | 7 | 6 | 5 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 | 1 | 1 |
| 17.0 | 132 | 82 | 55 | 38 | 28 | 21 | 16 | 13 | 10 | 8 | 7 | 6 | 5 | 4 | 3 | 3 | 3 | 2 | 2 | 2 | 2 | 1 | 1 |
| 16.0 | 157 | 98 | 66 | 46 | 34 | 25 | 19 | 15 | 12 | 10 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 2 | 2 | 2 | 2 | 2 |
| 15.0 | 189 | 119 | 80 | 56 | 41 | 31 | 24 | 19 | 15 | 12 | 10 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 2 | 2 | 2 |
| 14.0 | 231 | 146 | 98 | 69 | 51 | 38 | 30 | 23 | 19 | 15 | 13 | 11 | 9 | 8 | 7 | 6 | 5 | 4 | 4 | 3 | 3 | 3 | 2 |
| 13.0 | 286 | 182 | 123 | 87 | 64 | 48 | 37 | 30 | 24 | 19 | 16 | 13 | 11 | 10 | 8 | 7 | 6 | 6 | 5 | 4 | 4 | 3 | 3 |
| 12.0 | 361 | 231 | 157 | 111 | 82 | 62 | 48 | 38 | 31 | 25 | 21 | 18 | 15 | 13 | 11 | 9 | 8 | 7 | 6 | 6 | 5 | 4 | 4 |
| 11.0 | 464 | 299 | 204 | 146 | 108 | 82 | 64 | 51 | 41 | 34 | 28 | 23 | 20 | 17 | 15 | 13 | 11 | 10 | 9 | 8 | 7 | 6 | 5 |
| 10.0 | 613 | 398 | 274 | 196 | 146 | 111 | 87 | 69 | 56 | 46 | 38 | 32 | 27 | 23 | 20 | 18 | 15 | 13 | 12 | 11 | 9 | 8 | 8 |
| 9.0 | 834 | 547 | 379 | 274 | 204 | 157 | 123 | 98 | 80 | 66 | 55 | 46 | 39 | 34 | 29 | 25 | 22 | 19 | 17 | 15 | 14 | 12 | 11 |
| 8.0 | ### | 782 | 547 | 398 | 299 | 231 | 182 | 146 | 119 | 98 | 82 | 69 | 59 | 51 | 44 | 38 | 34 | 30 | 26 | 23 | 21 | 19 | 17 |
| 7.0 | ### | ### | 834 | 613 | 464 | 361 | 286 | 231 | 189 | 157 | 132 | 111 | 95 | 82 | 71 | 62 | 55 | 48 | 43 | 38 | 34 | 31 | 28 |
| 6.0 | ### | ### | ### | ### | 782 | 613 | 490 | 398 | 328 | 274 | 231 | 196 | 169 | 146 | 127 | 111 | 98 | 87 | 78 | 69 | 62 | 56 | 51 |
| 5.0 | ### | ### | ### | ### | ### | ### | 953 | 782 | 650 | 547 | 464 | 398 | 344 | 299 | 262 | 231 | 204 | 182 | 163 | 146 | 132 | 119 | 108 |

Hydraulic Retention Time (min)

**Max F Coli and Max Flow**

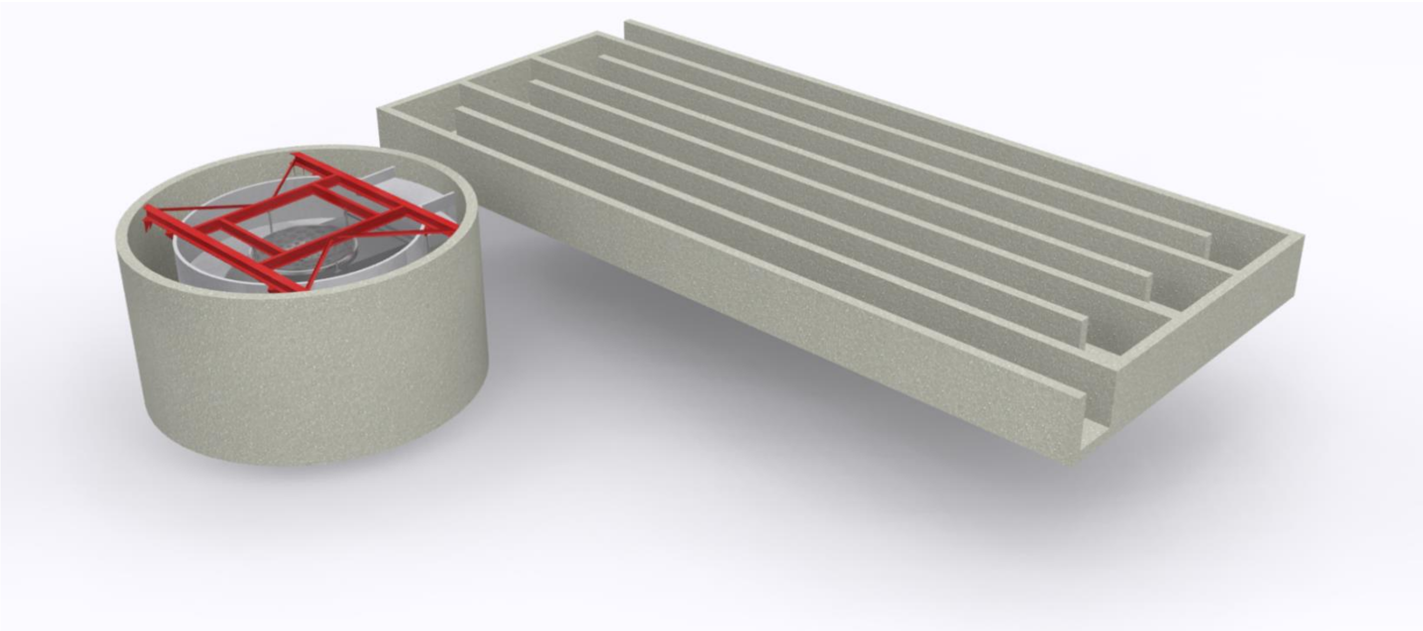
| Chlorine Dose (mg/l) | 5.0 | 6.0 | 7.0 | 8.0 | 9.0 | 10.0 | 11.0 | 12.0 | 13.0 | 14.0 | 15.0 | 16.0 | 17.0 | 18.0 | 19.0 | 20.0 | 21.0 | 22.0 | 23.0 | 24.0 | 25.0 | 26.0 | 27.0 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 22.0 | 361 | 231 | 157 | 111 | 82 | 62 | 48 | 38 | 31 | 25 | 21 | 18 | 15 | 13 | 11 | 9 | 8 | 7 | 6 | 6 | 5 | 4 | 4 |
| 21.0 | 408 | 262 | 178 | 127 | 94 | 71 | 55 | 44 | 35 | 29 | 24 | 20 | 17 | 15 | 13 | 11 | 9 | 8 | 7 | 7 | 6 | 5 | 5 |
| 20.0 | 464 | 299 | 204 | 146 | 108 | 82 | 64 | 51 | 41 | 34 | 28 | 23 | 20 | 17 | 15 | 13 | 11 | 10 | 9 | 8 | 7 | 6 | 5 |
| 19.0 | 532 | 344 | 236 | 169 | 125 | 95 | 74 | 59 | 48 | 39 | 33 | 27 | 23 | 20 | 17 | 15 | 13 | 11 | 10 | 9 | 8 | 7 | 6 |
| 18.0 | 613 | 398 | 274 | 196 | 146 | 111 | 87 | 69 | 56 | 46 | 38 | 32 | 27 | 23 | 20 | 18 | 15 | 13 | 12 | 11 | 9 | 8 | 8 |
| 17.0 | 712 | 464 | 320 | 231 | 172 | 132 | 103 | 82 | 67 | 55 | 46 | 38 | 33 | 28 | 24 | 21 | 18 | 16 | 14 | 13 | 11 | 10 | 9 |
| 16.0 | 834 | 547 | 379 | 274 | 204 | 157 | 123 | 98 | 80 | 66 | 55 | 46 | 39 | 34 | 29 | 25 | 22 | 19 | 17 | 15 | 14 | 12 | 11 |
| 15.0 | 986 | 650 | 452 | 328 | 246 | 189 | 149 | 119 | 97 | 80 | 67 | 56 | 48 | 41 | 35 | 31 | 27 | 24 | 21 | 19 | 17 | 15 | 14 |
| 14.0 | ### | 782 | 547 | 398 | 299 | 231 | 182 | 146 | 119 | 98 | 82 | 69 | 59 | 51 | 44 | 38 | 34 | 30 | 26 | 23 | 21 | 19 | 17 |
| 13.0 | ### | 953 | 670 | 490 | 370 | 286 | 226 | 182 | 149 | 123 | 103 | 87 | 74 | 64 | 55 | 48 | 42 | 37 | 33 | 30 | 27 | 24 | 21 |
| 12.0 | ### | ### | 834 | 613 | 464 | 361 | 286 | 231 | 189 | 157 | 132 | 111 | 95 | 82 | 71 | 62 | 55 | 48 | 43 | 38 | 34 | 31 | 28 |
| 11.0 | ### | ### | ### | 782 | 595 | 464 | 370 | 299 | 246 | 204 | 172 | 146 | 125 | 108 | 94 | 82 | 72 | 64 | 57 | 51 | 46 | 41 | 37 |
| 10.0 | ### | ### | ### | ### | 782 | 613 | 490 | 398 | 328 | 274 | 231 | 196 | 169 | 146 | 127 | 111 | 98 | 87 | 78 | 69 | 62 | 56 | 51 |
| 9.0 | ### | ### | ### | ### | ### | 834 | 670 | 547 | 452 | 379 | 320 | 274 | 236 | 204 | 178 | 157 | 139 | 123 | 110 | 98 | 88 | 80 | 72 |
| 8.0 | ### | ### | ### | ### | ### | ### | 953 | 782 | 650 | 547 | 464 | 398 | 344 | 299 | 262 | 231 | 204 | 182 | 163 | 146 | 132 | 119 | 108 |
| 7.0 | ### | ### | ### | ### | ### | ### | ### | ### | 986 | 834 | 712 | 613 | 532 | 464 | 408 | 361 | 320 | 286 | 256 | 231 | 208 | 189 | 172 |
| 6.0 | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | 891 | 782 | 690 | 613 | 547 | 490 | 441 | 398 | 361 | 328 | 299 |
| 5.0 | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | ### | 953 | 862 | 782 | 712 | 650 | 595 |

Hydraulic Retention Time (min)

It is also possible to monitor flow data and adjust the disinfectant dosing accordingly.

## Space Saving

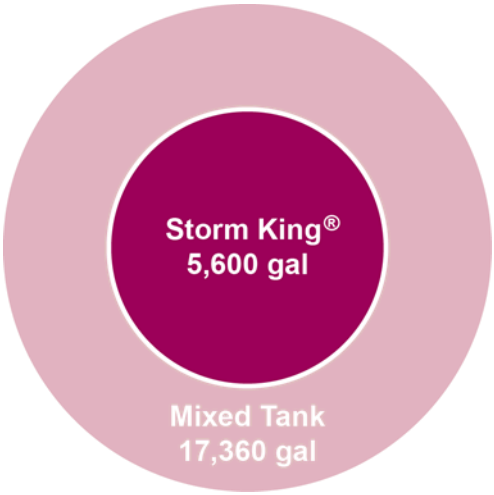
The Storm King® represents a huge saving in land requirements, with the same volume of contact vessel taking a quarter of the space required for a conventional tank, along with using just 30 to 35% of the concrete volume for construction. A typical serpentine tank arrangement is shown below; it has a width to depth to length ration of 1:1:140 (USEPA 1986). Hydro International's Storm King® is shown alongside to give a comparison.

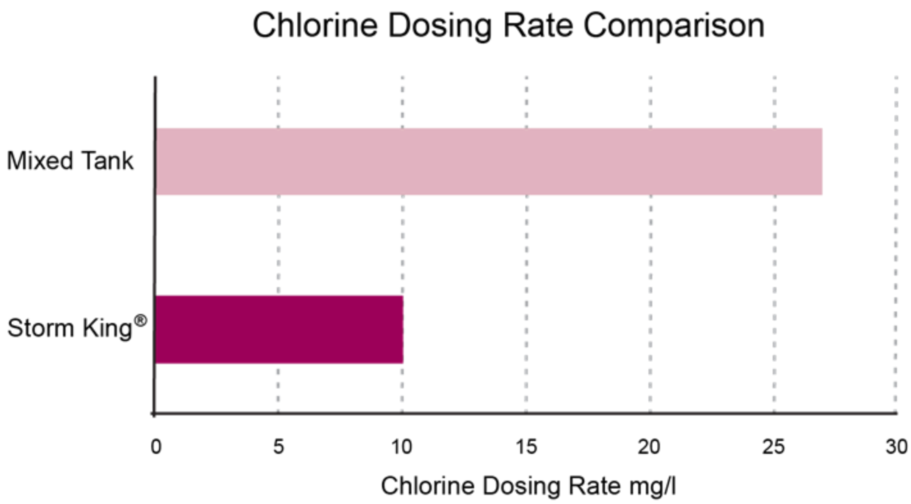


25.5' (7.75m) diameter tank. Water depth = 11.5' (3.5m), allow 10" (250mm) freeboard, and 10" (250mm) base slab. All walls 10" (250mm)

67.25' (20.5m) x 29.5' (9.0m) tank. Water depth = 3.25' (1.0m), allow 10" (250mm) freeboard, and 10" (250mm) base slab. All walls 10" (250mm)

Due to the Storm King® unit's superior residence time distribution characteristic and its solids removal and associated microbial properties, the Storm King® provides exceptional savings in both disinfectant dosing and reactor volume. To achieve the same disinfection performance as the Storm King® a conventional tank would have to be either three times as large, or have its dosing rate increase by 170%.



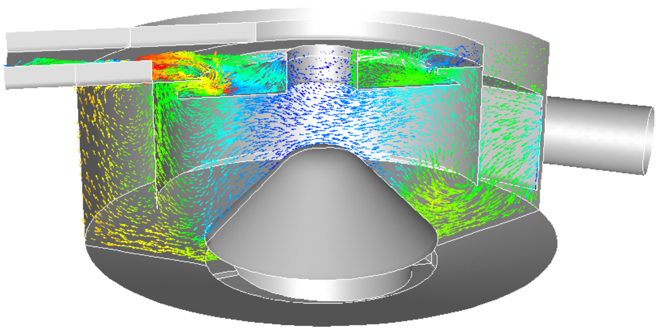



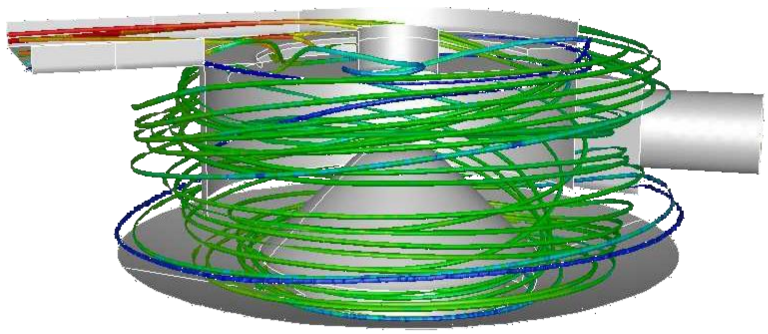

This represents a large saving in concrete costs and time on site, and allows the use of precast concrete segments, again saving time and money.

# Grit and Solids Removal

Because the Storm King®, has a controlled flow regime and resulting elongated flow path which encourages grit and solids to settle whilst disinfecting the flow, this allows the unit to combine its disinfection duties with total suspended solids and grit removal.  It also eliminates the build-up of grit and solids in the contact tank meaning that no prior separate removal stage is required such as a micro-strainer or other pre-treatment devices.

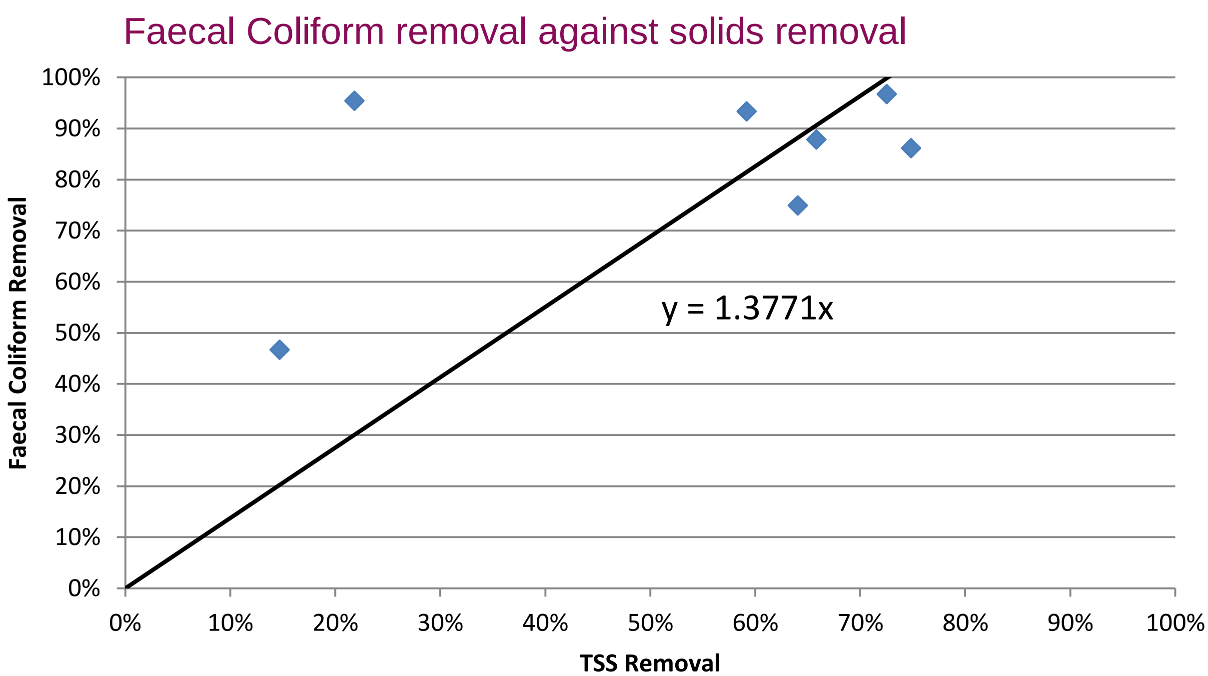
The Storm King® offers 50% or more cost savings over micro-strainers (USEPA 1979) treating the same flow and eliminates the need for a separate disinfectant contact tank.





# Microbial reduction through solids removal

Based on the results generated from 5 years monitoring of the full scale Storm King® installation at Columbus, GA site, a strong link has been observed between total suspended solids removal (TSS), and removal of coliform bacteria.  Typically 1.4% of coliforms are removed for every 1% of TSS removed. This shows a very high affinity for the solid material to harbour the bacteria, and thus removal of the solid material dramatically reduces the microbial load on the disinfected flow.  Solids removal is typically in the range of 60 to 75%, and the associated microbial reduction was found to be in the range 75 to 97%.  Lower removals of solids are typically seen at higher flow rates when the settling and retention times are lower and the influent flows are more dilute.



This removal can be factored into the model to allow for a reduction of the initial load. We would suggest that this is set at 75% as standard, representing a 0.6 log kill due to solids separation.

## Mixing

It is vitally important that sufficient initial rapid mixing occurs of the disinfectant with the wastewater (USEPA 1973) with the "G" value often used to assess this aspect of the process which is known as the velocity gradient.

$G = \sqrt{(P / \mu V)}$ (Metcalf and Eddy 2004)

Where:

G is the average velocity gradient ($s^{-1}$)

$\mu$ is the dynamic viscosity ($Ns/m^2$)

P is the power input (W)

V is the volume ($m^3$)

Water viscosity changes with temperature, and therefore has an impact on the velocity gradient. (Perry 1997)

For practical purposes it has been found that injecting the chemical disinfectant in a well-mixed region upstream of the Storm King® (eg. Diversion Chamber) is sufficient to provide the initial rapid mixing. The Storm King® has a tapering velocity gradient field which has been found to be good for effective contacting. Mechanical or static mixers could also be used but could suffer from problems associated with screenings in the flow.

It has been shown that "G" values of $500s^{-1}$ or more, offer sufficient mixing with no additional advantage offered at higher velocity gradients (Lee 2002).

## References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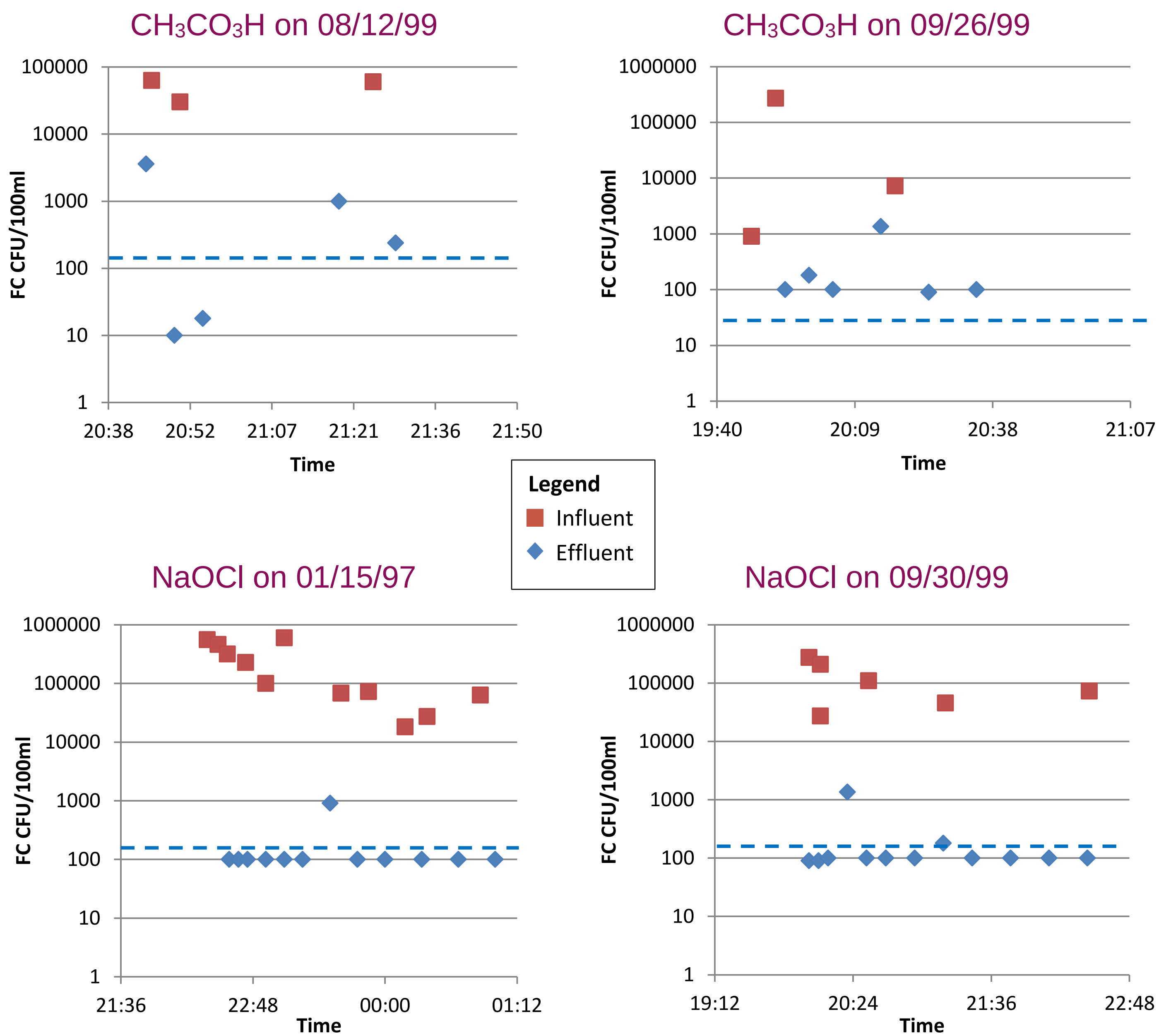
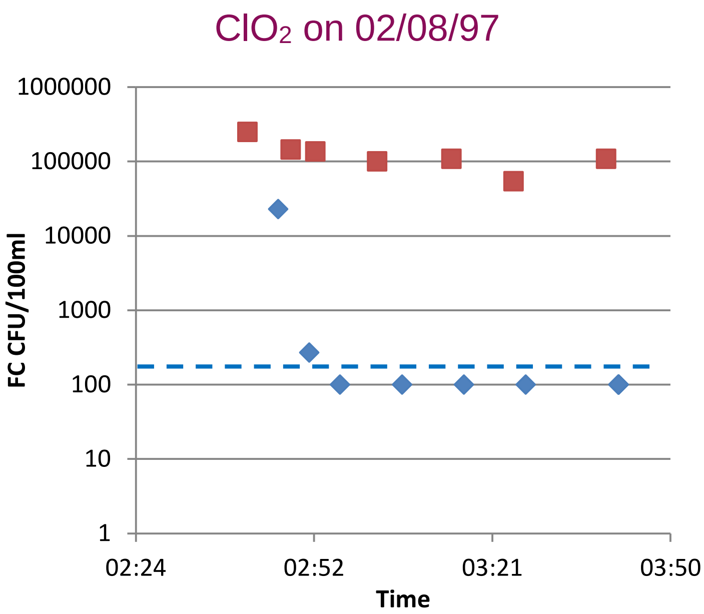
# Case Studies

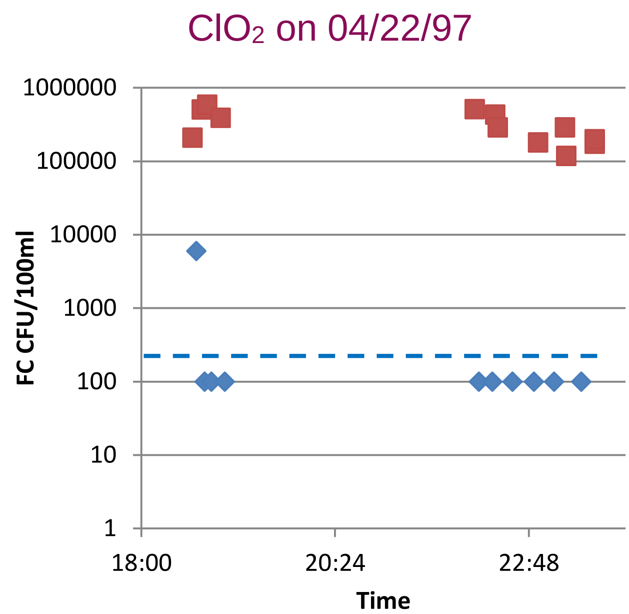
## Columbus, GA

Columbus Advanced Demonstration Facility (ADF) featured a number of identical Storm King® units operating with different disinfectants; these were Sodium Hypochlorite (NaOCl), Chlorine Dioxide ($ClO_2$), and Peracetic Acid ($CH_3CO_3H$ ).

The study showed that the required effluent standard could be met with any of the disinfectants. Typical dosing values were in the range of 7 to 15 mg/l. The facility was designed to handle 48 mgd, but has a hydraulic capacity of 144 mgd; 15.8 minutes to 5.3 minutes hydraulic retention time respectively.





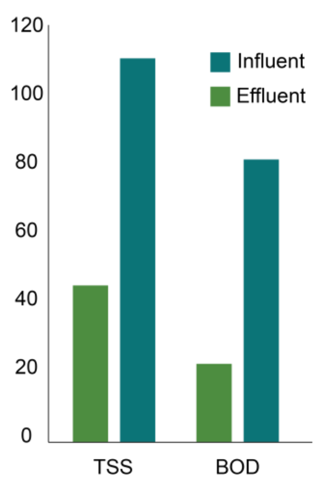




The full report on the Columbus ADF was published by WERF in 2003.

## Saco, ME

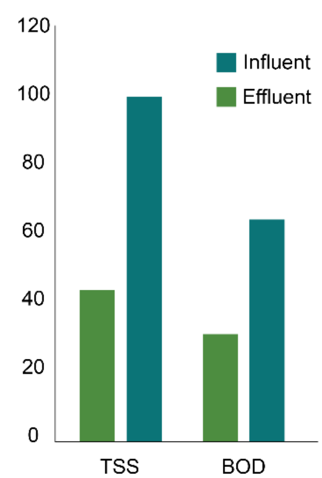
The Saco, Maine CSO treatment facility, which consist of a 22 foot diameter Storm King® was commissioned in 2006. It was designed for a maximum flow of 5.63 mgd, and has been dosed with sodium hypochlorite for disinfection.

The design hydraulic retention time was 8 minutes.




| | Influent (mg/l) | Effluent (mg/l) | % Removal |
|---|---|---|---|
| **TSS** | 111 | 43.8 | 61 |
| **BOD** | 81.8 | 21.2 | 74 |

Note that this chart is the 2007 Nor'easter where the system ran for 5 days continuously.




| | Influent (mg/l) | Effluent (mg/l) | % Removal |
|---|---|---|---|
| **TSS** | 100 | 42.1 | 58 |
| **BOD** | 65.6 | 29.1 | 56 |

Note that this chart is the average of all storm events to date.

The annual data summaries for post construction monitoring over a period of more than four years, shows fairly consistent average effluent concentrations for both BOD and TSS with the observed relatively high BOD removals repeated in successive years. The figure above (which shows the observed overall average TSS and BOD removals over the period January 2007 to March 2011) and the table below clearly highlight that even for the periods when the influent BOD concentrations have been low; removals have been above the norm of 50% TSS and 20% BOD. It is surmised that the observed high BOD removals may be a function of the additional effects of the integral self-cleaning fine screen mesh within the Storm King® unit.

Data summaries for January 2007 to March 2011

| Year | Number of CSO Events | Avg. Influent BOD (mg/l) | Avg. Effluent BOD (mg/l) | BOD Removals (%) | Avg. Influent TSS (mg/l) | Avg. Effluent TSS (mg/l) | TSS Removals (%) | Avg. Faecal Count (cfu/100ml) |
|---|---|---|---|---|---|---|---|---|
| **2007** | 19 | 86.3 | 29.4 | 66 | 130.3 | 48.8 | 63 | 110 |
| **2008** | 21 | 84.5 | 30.1 | 64 | 110.2 | 34.8 | 68 | 51 |
| **2009** | 18 | 51.0 | 34.2 | 33 | 93.2 | 47.5 | 49 | 129 |
| **2010** | 22 | 54.5 | 30.8 | 44 | 87.7 | 38.6 | 56 | 90 |
| **2011*** | 4 | 51.6 | 21.2 | 59 | 78.8 | 40.8 | 48 | 84 |

*Note: 2011 is not a full year's worth of data

The observed average annual faecal counts are also below the consent requirements of 200 colony forming units (cfu) per 100ml for the site; confirming the effectiveness of the Storm King® as a contact chamber for high-rate disinfection of CSO and other wet-weather flows.

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