OPTIMISED DESIGN OF STORMWATER TANKS

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DESIGN OF STORMWATER TANKS

Recommendations and layout

The concept of storm water detention is to temporarily store excess storm water runoff. This is to avoid hydraulic overload of the sewer system, which could result in the flooding of roads and buildings with untreated wastewater or its release directly into the environment, causing pollution. When space is available in the sewer system, the detained water is released at a rate not exceeding the capacities of the sewer system, and the tank should be cleaned ready for the next flush.

THE CHALLENGE AHEAD

Climate change is increasingly the cause of extreme weather phenomena around the world, for example extreme rainfall. This challenges the existing sewer system, not least because an increase in rain intensity of 40 to 60 % will reduce the return period of severe flooding events. Stormwater tanks can store much of this excess rainwater, thereby reducing the hydraulic load on the existing sewers. Properly sited, such tanks can reduce the need for expensive renovation of the existing sewer system.

Retention of these extreme peak flows of rainfall is also a major challenge because of the extent of paved or impermeable areas in urban areas. In these situations, water cannot naturally seep into the ground as normal, and instead water is guided into the existing sewer system. This creates a substantial hydraulic load in the pipes network and at the wastewater treatment plant. Furthermore, paved and impermeable areas also collect more airborne pollutants which are washed off along with rainwater.

Storm water runoff is the term normally used for this kind of runoff water. Storm water is of concern for two main reasons: one is related to the volume and timing of the runoff water; and the other is related to potential contaminants that the water may be carrying. As we have seen above, both can be expected to increase.

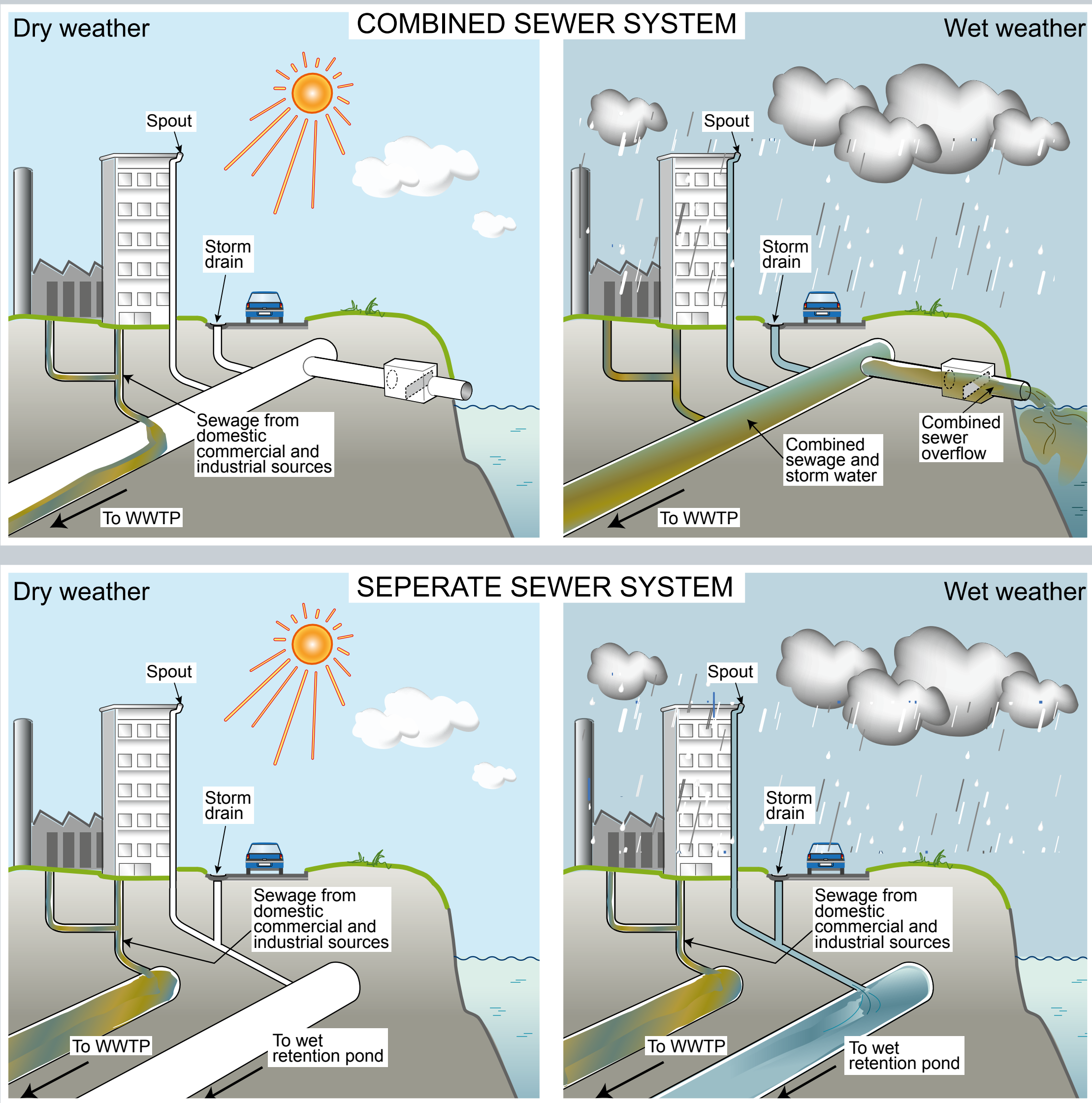


Figure 1:

Combined (top) and separate (bottom) sewer systems during dry and wet weather flow.

RETAINING STORM WATER

Storm water is collected in the sewer network. A sewer network can either be a combined system or a separate stormwater system (Figure 1,). The latter is of no interest for this guideline, as the storm water from this system is often guided directly to the recipient or into wet retention ponds. However, storm water from the combined sewer system is a more complex issue and can cause environmental, aesthetic and hygiene problems for the recipients, in the form of combined sewer overflows of untreated wastewater, because the systems are not constructed to cope with these large water flows.

In many parts of the world, there is now an acknowledgement of and increased focus on these issues and requirements through local legislation for discharge from combined sewers has become common. At a general level, this greater awareness can clearly be seen in efforts to prevent and reduce pollution, promote sustainable water use, protect the aquatic environment, improve the status of aquatic ecosystems, and mitigate the effects of floods.

HEALTH, SAFETY AND THE ENVIRONMENTAL ISSUES

Of major concern to regulatory bodies are the health and safety issues for populations living close to waters with bacteriological and chemical pollution. The pollution resulting from these discharges, even though only brief and periodical, is also in focus because it can cause severe ecological consequences and impact more heavily on the environment than the steady load from a wastewater treatment plant. Minimising the overflows from combined sewers can thereby improve water quality and ecological stability in many ways.

Untreated wastewater can also back up in the sewer system and result in backflow into buildings and basements, for example through toilets and drains and result in property damage. The concern here is possible economical losses for private homes, companies and public buildings due to the destruction of property, of contents and the cost of cleaning.

STORMWATER TANKS AN EFFECTIVE SOLUTION

Stormwater tanks are an effective way of reducing peak flow and equalising flow rates from storm water runoffs in the sewer system. Placed strategically, stormwater tanks mean better utilisation of the existing sewer system, allow for intelligent management of storm water flows, and ultimately save on infrastructure investments.

Stormwater tanks are a cost-effective solution, because sewer lines are already constructed and generally have a substantially remaining lifetime, and replacing existing pipes in an urban environment is – in addition to being very expensive – troublesome.

Stormwater tanks can be relatively easily adapted to the sewer system, and during heavy rain the sewer system is relieved by guiding excess storm water to the stormwater tank for temporary storage (Fig. 2). All this illustrates the advantages of self-cleaning, pump-managed stormwater tanks.

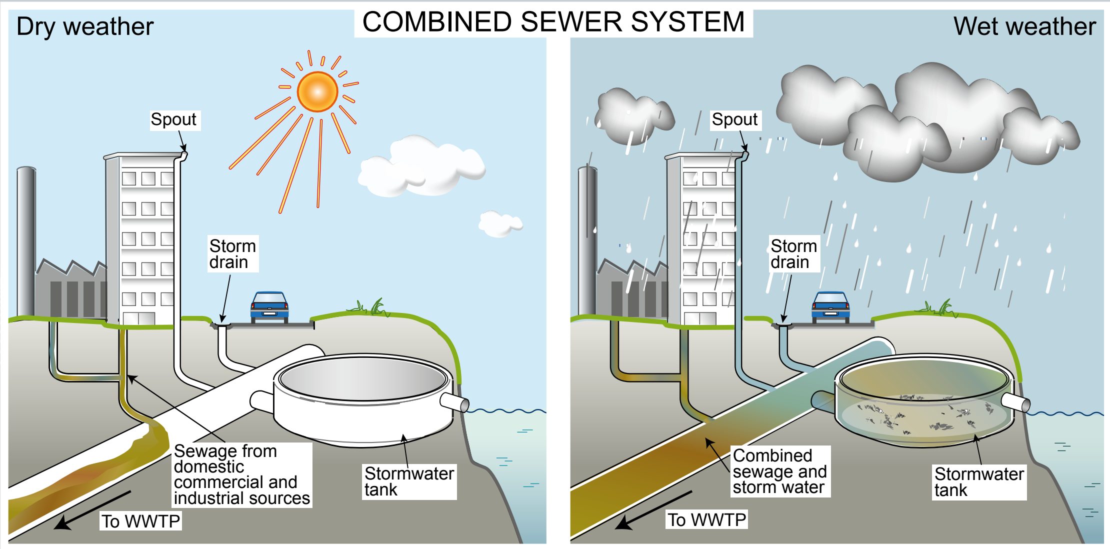


Figure 2:

Combined sewer systems with an integrated stormwater tank during dry and wet weather flow.

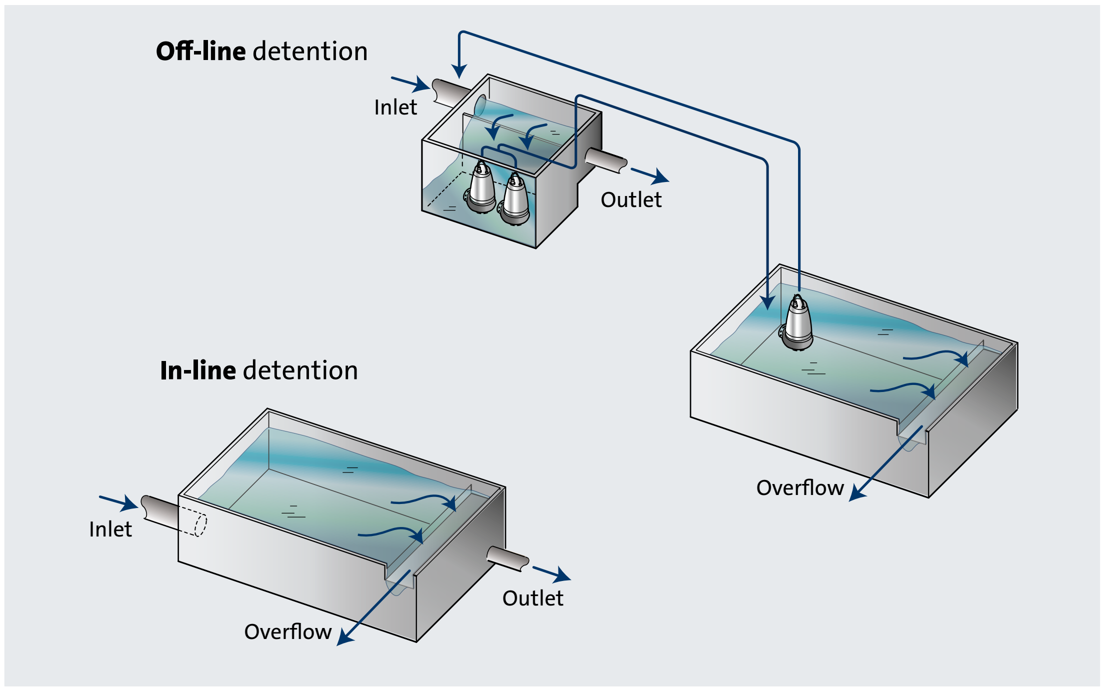


Figure 3:

In-line and off-line storage

IN-LINE AND OFF-LINE RETENTION

Stormwater tanks are classified according to how they are connected to the sewer system. For stormwater tanks connected in series with the conveyance system, the term in-line storage or detention is used. Storage facilities connected in parallel to the sewer system are termed off-line storage or detention (Fig. 3).

With in-line detention, both dry and wet weather flow passes through the tank. The outlet for in-line detention tanks has less capacity than the inlet, and consequently flow passes through the tank undetained until the inflow rate exceeds the outlet capacity. The excess inflow is then stored within the tank until the inflow rate decreases, where the detained water then empties through the outlet.

Off-line storage is connected in parallel to the sewer pipe, and as such dry weather flow bypasses the storage tank, leaving the stormwater tank empty between storms. Off-line storage is first achieved when a predetermined flow rate is exceeded and the flow from the conveyance system is diverted into the stormwater tank by means of pumping or gravity. The detained water is stored in the tank until sufficient conveyance or treatment capacity becomes available downstream and the water can be pumped back.

Inflow from a storm water runoff event entering the stormwater tank carries organic and inorganic matter. This can include macro pollutants such as fine particles, vegetation and litter or micro pollutants such as nutrients, bacteria, heavy metals and chemicals. The usual definition of all these materials together is total solids (TS), which consists of a suspended (TSS) and a dissolved (TDS) fraction. For storm water detention, this incoming material is left to settle during the detention period. Only a fraction of the suspended solids will settle during retention in the tank whereas the rest will remain in suspension (Fig. 4).

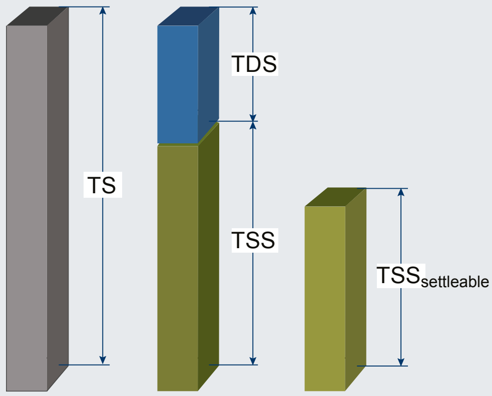


Figure 4:

Diagram showing the fraction of the total solids (TS) that will settle (TSS settleable) in the stormwater tank during retention.

FACTS:

Detaining water for a period of time can also be utilised in applications other than the temporary storage of storm water in the sewer system:

- **Wastewater treatment plants:** Ensuring efficient treatment of wastewater a constant hydraulic load must be provided throughout the cleaning processes securing final effluent quality. Inflows of water exceeding the capacity can then be temporary stored in a detention tank.
- **Large blocks of flats and buildings:** Discharges to the sewer system are often subject to limits due to the capacity of the public sewer network. If the hydraulic load is exceeded, detention tanks can be used for temporary storage.
- **Discharges from factories:** Batch volumes of process water with a certain chemical or physical property must sometimes be stabilised or equalised before discharge to the sewer system. This is to ensure that the processes taking place at the receiving wastewater treatment plant are not disturbed.

ENSURING EFFECTIVE CLEANING

If the detained water is conveyed directly back into the sewer system, the majority of the settled matter will stay in the tank, where it will build up. Once established, sediment deposits in the tank are difficult to remove, even with pressure cleaning equipment, and these deposits will take up storage capacity. If the settled matter is not removed from the tank, the tank will also appear dirty and poorly maintained. Furthermore, anaerobic decomposition of the detained organic matter due to biological activity creates unpleasant odours and toxic gases from the stormwater tank.

The accumulated matter contains various toxic compounds adsorbed to the settled organic particles as well as a variety of pathogenic bacteria. Manual cleaning in connection with tank operation is therefore problematic and should be eliminated. Instead, an effective, automatic and controlled cleaning of the stormwater tank should be implemented.

Cleaning efficiency is however dependent on stormwater tank design. Due to the flexibility when building with concrete, which often is used for the construction of stormwater tanks, these storage facilities can assume many forms and be fitted in where space is available. Describing them all is not feasible and this guideline only considers rectangular and circular tanks, but the principles described can be transferred to other shapes and forms, with modifications.

Stormwater tanks are most often flat-bottomed, which are not self-cleaning and therefore require special equipment. For automatic cleaning of these tanks different types of equipment are available, such as mechanical bottom scrapes, and single flush or continuous flush water systems.

Mechanical scrapers keep a clearance from the bottom of the tank, leaving material on the tank floor which will give rise to the odour problems described above. This system will therefore not be suitable for stormwater tanks that are emptied between storm water events. Compared to the single flush system, the continuous flush system has the advantage that it can continue the flushing cycle until all detained matter has been removed from the tank.

Relatively cheap, flexible and automatic cleaning with a continuous flush system is obtained by installing Flushjets. This type of equipment is categorised as a continuous flush system that can easily be adjusted to fit most stormwater tanks. Grundfos Flushjets are available in two different versions: the Water/Water ejector (Flushjet WW), and the Water/Air ejector (Flushjet WA). The Flushjet does not need an external source of fresh water supplied for cleaning, as it uses the detained water already in the tank for flushing. This completely circumvents the possible problems of backflow into the potable water system.

To ensure that the effective and automatic cleaning of the stormwater tank runs smoothly, it is important that the tank is properly designed, both in regards to equipment, physical design and controls. To aid the process of creating a durable solution, this handbook aims to help provide an overview of some of the important points regarding equipment used for automatic control, stormwater tank design, placement of equipment and automatic operation.

THE GRUNDFOS FLUSHJET RANGE

FLUSHJET WA WITH LONGER-REACHING JET AND MIXED WITH AIR

FLUSHJET WW WITH GREATER FLOW FOR WIDER TANKS

STORMWATER TANKS IN DUTY-MODE OF OPERATION

The variation in stormwater tank design that might arise due to differences in construction means that the operation of each stormwater tank must be considered as a unique case. However, regardless of whether the tank is renovated or newly constructed, the determining factor for the effective use of the structure for efficient cleaning is the hydraulics of the system, as it is the flow of water that cleans the tank.

The hydraulics of the system require the consideration of filling capacity, mixing, cleaning and emptying as well as the retention time of the storm water runoff. Equipment installed in the tank can directly influence the hydraulics, and the selection of equipment must address these issues.

Grundfos has a strong tradition in using state-of-the-art simulation tools to improve our products and has more than 15 years of experience making simulations using computational fluid dynamics (CFD) to describe flow patterns in for example pumps and pumping stations. Grundfos has utilised CFD tools for describing, optimising and visualising the hydraulic processes that takes place during stormwater tank operation with the finite volume method (Figure 5). Simulations in this guideline have been made using the general purpose CFD software suite ANSYS CFX that combines an advanced solver with powerful pre- and post-processing capabilities.

The best practice for CFD modelling has been applied to generate the simulations shown here. This involves generating appropriate computation grids and selecting the relevant physical models.
The CFD models give the possibility for studying details in the hydrodynamics of the Flushjet, which is not possible with traditional experimental methods. Figure 5 shows examples of flow patterns which would take weeks to measure manually. The resulting simulations can – with the use of vector or contour plots in various intersections of the tank – provide an insight into how the hydraulics act in the tank.

The colours of the arrows and contours show the magnitude of the chosen variable according to the scale in the picture. Furthermore, the arrows on the vector plots show how the direction of flow of water is in the tank at the specific conditions.

FILLING

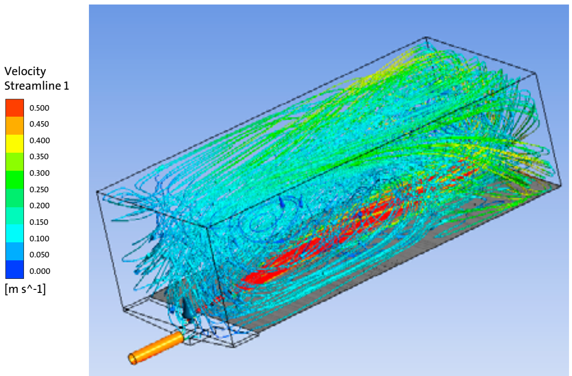
When the tank is being filled, two conflicting parameters are important to provide relief for the sewer system and let detained material settle. Inflow to the stormwater tank should take place at a pace that ensures the sewer system delivering water to the tank does not become overloaded, with the consequences that follow. On the other hand, the inflow should not arrive at a pace or in a manner that makes turbulence in the tank an issue for the settling of detained material, should an overflow from the tank occur.

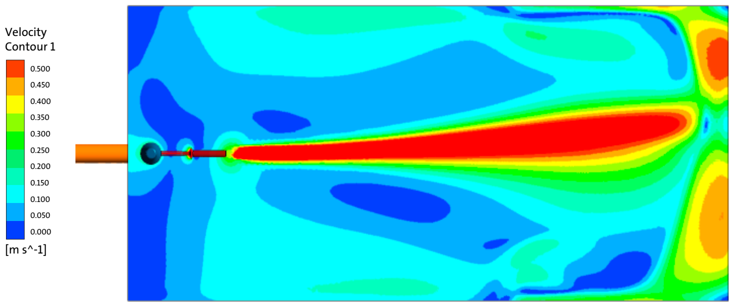
The extent to which pumps should be used in stormwater tank operation depends on site topography, vertical fall in the sewer system and the amount of control that is desired for the flow in the system. In some cases, where site topography allows it, gravity can be used to cope with the flow either in or out of the tank. However this strategy does not provide as tight a control with the runoff as is possible when applying pumps for the task.

The pumps chosen can be either centrifugal or propeller pumps, depending on the flow and head required. The free passage of the impeller in the pump should however be considered to avoid possible clogging issues. Some sewer systems and stormwater tanks have incorporated screens to trap major impurities, while other systems let everything pass and will either pass through or block the pumps operating the system.

Figure 5:

CFD simulations can be used to describe the hydraulic processes taking place in the stormwater tank. At the top can be seen an example of a velocity vector plot and at the bottom a contour plot showing the water velocity at the bottom plate.





FIRST FLUSH

In the first minutes of a storm water runoff event, a batch of water termed the first flush will arrive. The first flush carries high concentrations of organic and inorganic matter to the stormwater tank. This material has accumulated in the sewer system or on the drained area during periods without rain. Absorbed in this material are different chemicals such as heavy metals and xenobiotics. These chemicals originate from the surfaces of roofs, drains, concrete areas and roads in the catchment areas.

Because of the intake of large amounts of organic and inorganic matter in the first period of a runoff event, it might be advantageous to divide larger stormwater tanks into separate sections, which are then filled successively and controlled by weirs, valves or other arrangements (Fig. 6). Filling the sections successively gives two advantages. Firstly, only the section(s) of the tank that have been filled must be cleaned and not the whole tank. Secondly, all major impurities are retained in the first section, minimising the risk of having suspended material in the effluent in the event of an overflow.

RETENTION TIME

Retention time of the stored water is controlled by available space in the sewer system, and this determines when water from the tank can be conveyed back. This can normally be done immediately after the storm water runoff event and the tank can be empty within 24-48 hours after the first inflow. During extended periods of detention, unintended issues such as odour problems might arise, resulting from the combination of wastewater quality, temperature and time.

Wastewater carried to the stormwater tank from the combined sewer system contains a certain load of organic matter. The organic matter in the detained water decomposes under the consumption of oxygen in the water phase due to biological activity. During extended periods of detention, oxygen is consequently depleted, which gives rise to the formation of anaerobic zones in the tank. At elevated water temperatures (15 ºC or above), the microorganisms speed up the decomposition of organic matter and thus the depletion of oxygen happens even faster. As oxygen in the water becomes limited, anaerobic decomposition of the organic matter will be the main mechanism for decomposition. Anaerobic decomposition creates foul smelling and flammable gasses such as hydrogen sulphide and methane that will emit to the surroundings from the stormwater tank or get trapped inside if the tank is covered, creating a hazardous environment.

The Flushjet used for cleaning can be supplied both with and without an aerated jet stream. Choosing a Flushjet WA will introduce air into the detained water, which might eliminate or postpone the formation of anaerobic zones and the inconveniences this might bring.

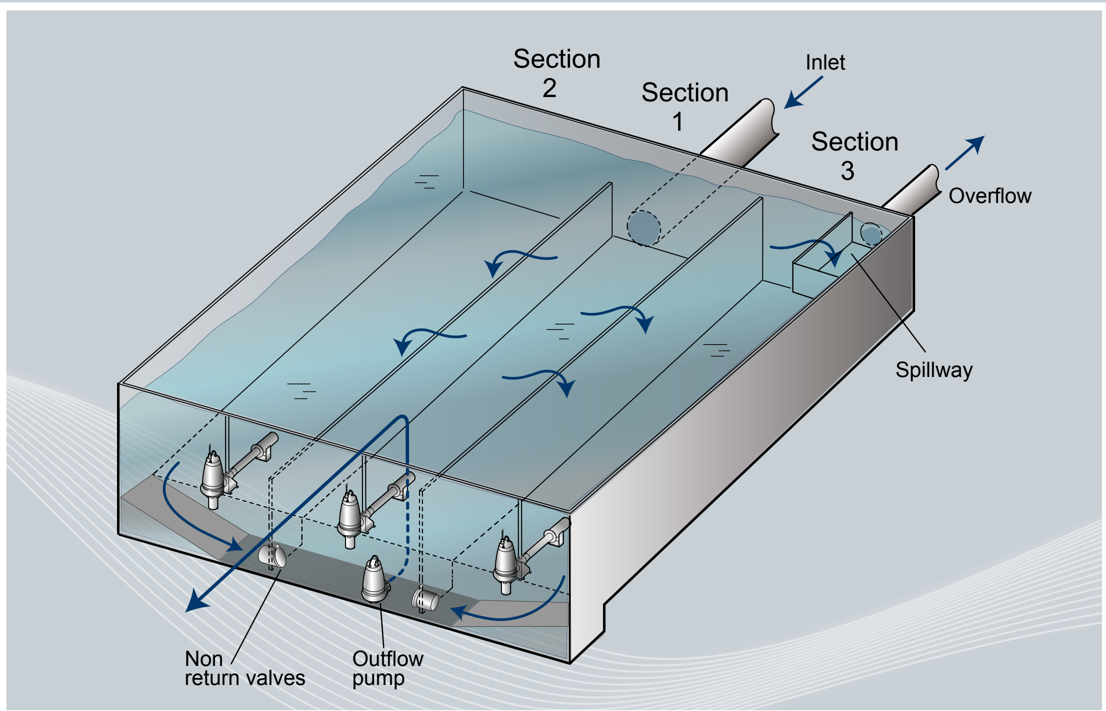
RISK FOR OVERFLOW

There is an economic consideration about how big the stormwater tank should be constructed, in relation to the expected inflow of storm water. Some storm water events will therefore exceed the capacity of the tank and an emergency overflow must consequently be incorporated.

Legislation setting up the environmental goals for the receiving waters and the degree of safety concerning health issues for the people living nearby

Figure 6:

Successive filling of a stormwater tank



FACTS:

Gas development problems related to anaerobic digestion of materials in storm water tanks:

- **Hydrogen sulphide (H_2S):** H_2S has a very characteristic odour and smells strongly like rotten eggs and flatulence. It is a highly toxic and flammable gas that is detectable in low concentrations (ppm). H_2S deadens the sense of smell in higher concentrations or after prolonged exposure. Respiratory paralysis and death may occur quickly at concentrations as low as 0.07% by volume in air.
- **Methane (CH_4):** CH_4 is a colourless and odourless gas at room temperature and atmospheric pressure. CH_4 is not toxic but it is highly flammable and may form explosive mixtures with air. CH_4 is a relatively potent greenhouse gas which contributes to global warming because it in the atmosphere is converted in to carbon dioxide and water.

now makes it mandatory in most places to monitor and report the number of overflows, duration, volume, etc., for each individual stormwater tank.

To avoid gross material flowing into the receiving waters, screens can be installed on the overflow to cope with this. The screens will trap impurities depending on the clearance and reduce organic pollution of the receiving water. In vulnerable areas, a further treatment of the overflow might be required before it is guided to the receiving waters. For this purpose, membranes, filters or disinfection equipment can be installed.

Disinfection of the overflow can eliminate bacteriological contamination and the hazards that bacteria can cause. Disinfection can be either chemical or physical. The chemical methods comprise dosing of chlorine or its derivatives as well as ozone, where a widely used physical method is exposure of the water to UV light. For disinfection of overflows from stormwater tanks, high-rate disinfection is often required to ensure adequate removal of pathogens from short-term high volume overflows.

The disinfection equipment must be able to be controlled based on intermittent high flows with variable temperatures, suspended solids concentrations and levels of microorganisms.

Due the presence of suspended solids in the detained water, it might be necessary to install screens or filters in front of the equipment. If these organic impurities are not removed, they will decrease the efficiency of the disinfection methods, simply by lowering the bacterial removal rate and furthermore will result in the formation of toxic by-products.

CLEANING AND MIXING

The principles for the automatic cleaning of stormwater tanks using Flushjets are described below. The cycles that take place in the tank during a storm water event from inflow of wastewater to the completely cleaned tank are described below. Automatic control of the installed equipment is normally done depending on water levels. Stormwater tank operation is basically divided into four periods:

1) a filling period where the inflow exceeds the outflow;
2) a settling period;
3) a depletion period where the tank empties when the outflow is greater than the inflow rate;
4) a cleaning period where the tank is flushed, cleaned and completely emptied.

(See figures 7-11).

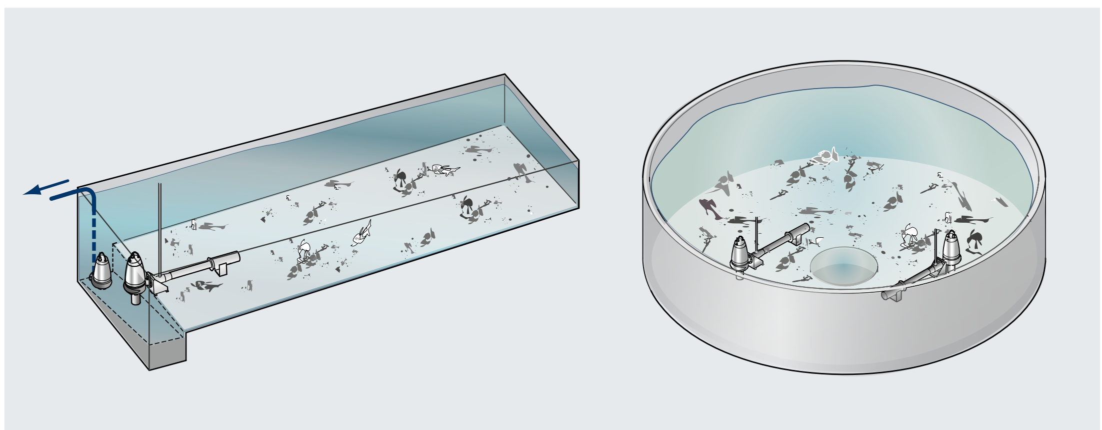


Figure 7:

Step 1-2: Filling of the tank and settling of detained material

Cleaning

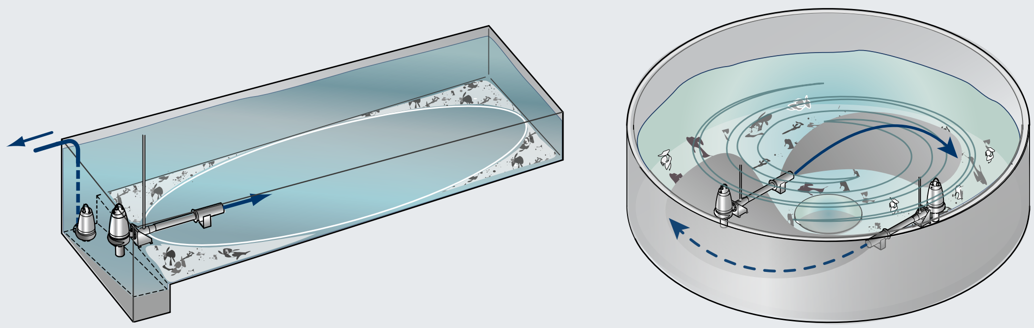
During the filling period it is desirable to let the organic and inorganic matter settle on the tank floor so it does not run into the recipient if overflow from the tank happens (Figure 7).

During the subsequent depletion period it is desirable to resuspend the settled material for transport back to the sewer network and further to the wastewater treatment plant for treatment.

In the depletion period mixing must therefore be provided, which can be done using Flushjets or a combination of Flushjets and mixers (see Figure 8).

Figure 8:

Step 2 – Mixing and resuspension of settled matter.



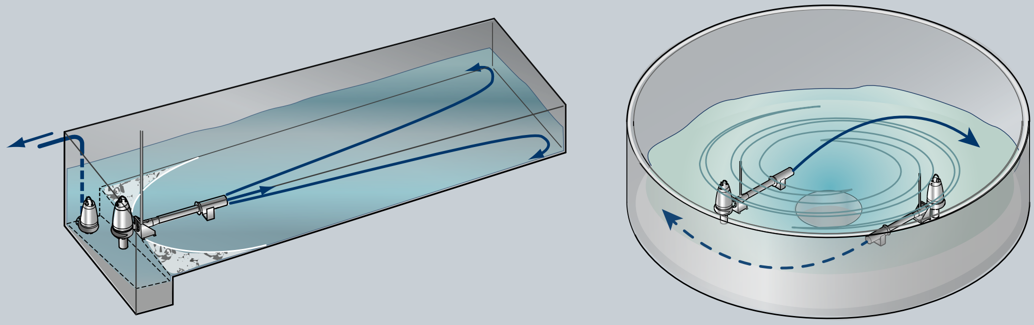
Rectangular tank:
Switching on the Flushjet ensures that the side walls and the centre area of the tank floor are kept free from deposits due to the mixing force provided by the installed equipment. A properly chosen Flushjet resuspends most of the settled matter in the tank, with only the corners as an exception.

Circular tank:
Switching on the Flushjet will start building the inertia of the circular movement which will clean the stormwater tank. In the direction of the jet stream the settled matter will be resuspend due to the mixing force provided by the Flushjet. Furthermore the side walls will also be scoured as a result of turbulence in the tank.

During the depletion period the water level is reduced by pumping the detained water back to the sewer system (see Figure 9). The force required for mixing the decreasing volume of water in the tank thereby also decreases. However as the Flushjet delivers an unchanged thrust force, this allows the Flushjet to resuspend the remaining settled matter in places further away from the machine.

Figure 9:

Step 3 – Resuspension and clearance of places further away from the Flushjet in the depletion period



Rectangular tank:
The excess thrust force during the depletion period is further assisted by an effect of a dynamic cleaning motion where the water jet oscillates from side to side, effectively resuspending settled material in the corner of the tank furthest away from the Flushjet (Figure 10).

Circular tank:
During the depletion period the circulation speed increases due to the excess power input. This ensures that all settled material at the tank periphery will be resuspended and dragged with the water towards the centre of the tank.

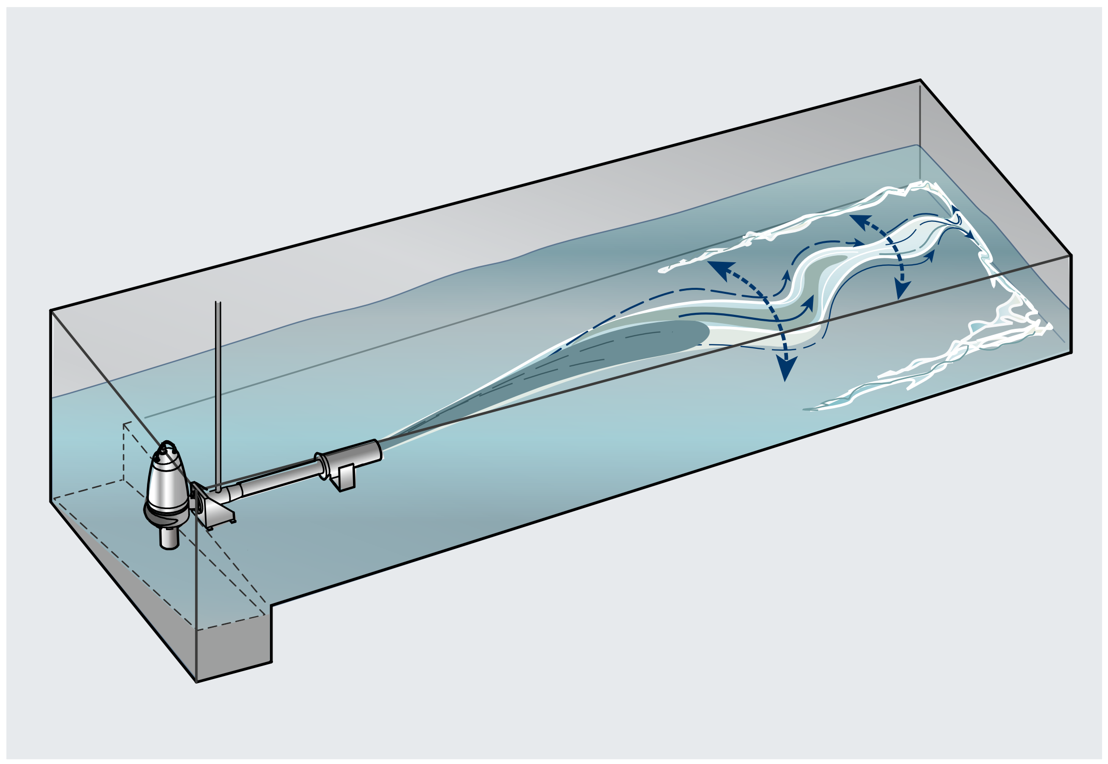


Figure 10:

The dynamic cleaning effect where the water jet oscillates from side to side can be visualised using transient CFD calculations.

When depletion of the tank is close to being completed the water level in the tank is between 30 - 60 cm and the Flushjet will be partially unsubmerged and the operational cycle proceeds into the cleaning period (see Figure 11).

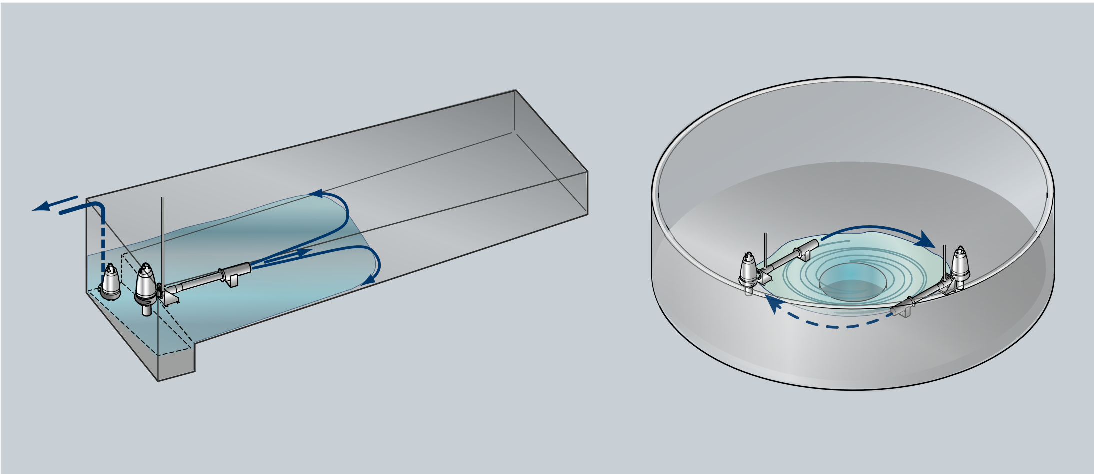


Figure 11:

Step 4 – Cleaning proximity of the Flushjet

Rectangular tank:
In the cleaning period the length of the jet stream decreases, reaching approximately the centre of the tank where a standing wave forms. This wave terminates the jet and spreads out the stream. As the water level decreases in the tank, the jet length from the Flushjet similarly decreases until the hydraulic jump disappears and the jet stream simply protrudes along the tank floor.

The back flow of water is now generated from the centre of the tank, gathering the solids in the proximity of the Flushjet and flushing them to the sump.

Circular tank:
As the Flushjet becomes unsubmerged the water jet length decreases. This implies that the water delivered from the Flushjet will be concentrated in the middle of the tank flushing any remaining material at the centre into the sump of the tank.

The sump of the stormwater tank can now be completely emptied by the outlet pump. All organic and inorganic matters are now removed from the tank. The tank is now thoroughly cleaned and eventual odour problems are totally eliminated.

MIXING

The hydrodynamics of the Flushjet makes it possible to both control the mixing and the cleaning of the tank at the same time. In the depletion period the detained water must be mixed to resuspend the settled matter and obtain an efficient cleaning. The Flushjet is capable of both. When submerged the Flushjet utilises the flow of water created in the ejector to act as a powerful mixer, resuspending the matter in the tank due to the thrust force and high power jet formed. At low water levels the Flushjet acts as a powerful flushing device, cleaning the tank floor and walls from organic matter, as explained in the section above.

The equipment installed in the stormwater tank must be sized to deliver a large enough water flow and thus a thrust force to mix the water volume of the stormwater tank. Choosing a Flushjet with a too large water flow will not enhance cleaning efficiency but only waste energy in for example the mixing phase of the cleaning cycle, as illustrated in Figure 12.

The velocity gradients, as shown on the simulations below, will give rise to a certain shear stress at the tank bottom, which at large velocities will be sufficient to keep the bottom plate free from deposits.

For a tank having a water level of 4 meters, a Flushjet delivering a water flow of 25 l/s is insufficient to create a high enough velocity – and therefore sufficient mixing – in the tank to provide an acceptable coverage of the tank corners furthest away from the Flushjet.

Increasing water flow to 75 l/s will result in energy being wasted at the tank wall and water surface, as there is a high velocity when the contour colours are matched to the legend in the figure below. However, a performance of 50 l/s seems to be suitable, as the water jet of the Flushjet is sufficient to reach all the way to the backwall with an appropriate velocity to sweep the corners, resuspending the settled material without wasting energy on the backwall and water surface.

Even though velocities in the middle part of the tank seem low compared to a performance of 75 l/s, this has no effect on the cleaning efficiency. This is due to the fact that this area of the tank is being cleaned during the end of phase 3 and start of phase 4, where the water flow of the ejector is concentrated in this area. Furthermore, at a performance of 50 l/s the water velocity in the area above the sump is low which favours sedimentation. This means that materials will collect in the sump where it will be carried away through the outlet pipe.

If instead of mixing the entire volume it is only necessary to mix a predefined volume of the stored water, a Flushjet with a smaller capacity can be used. However when choosing this solution it is important to make sure that materials detained in the

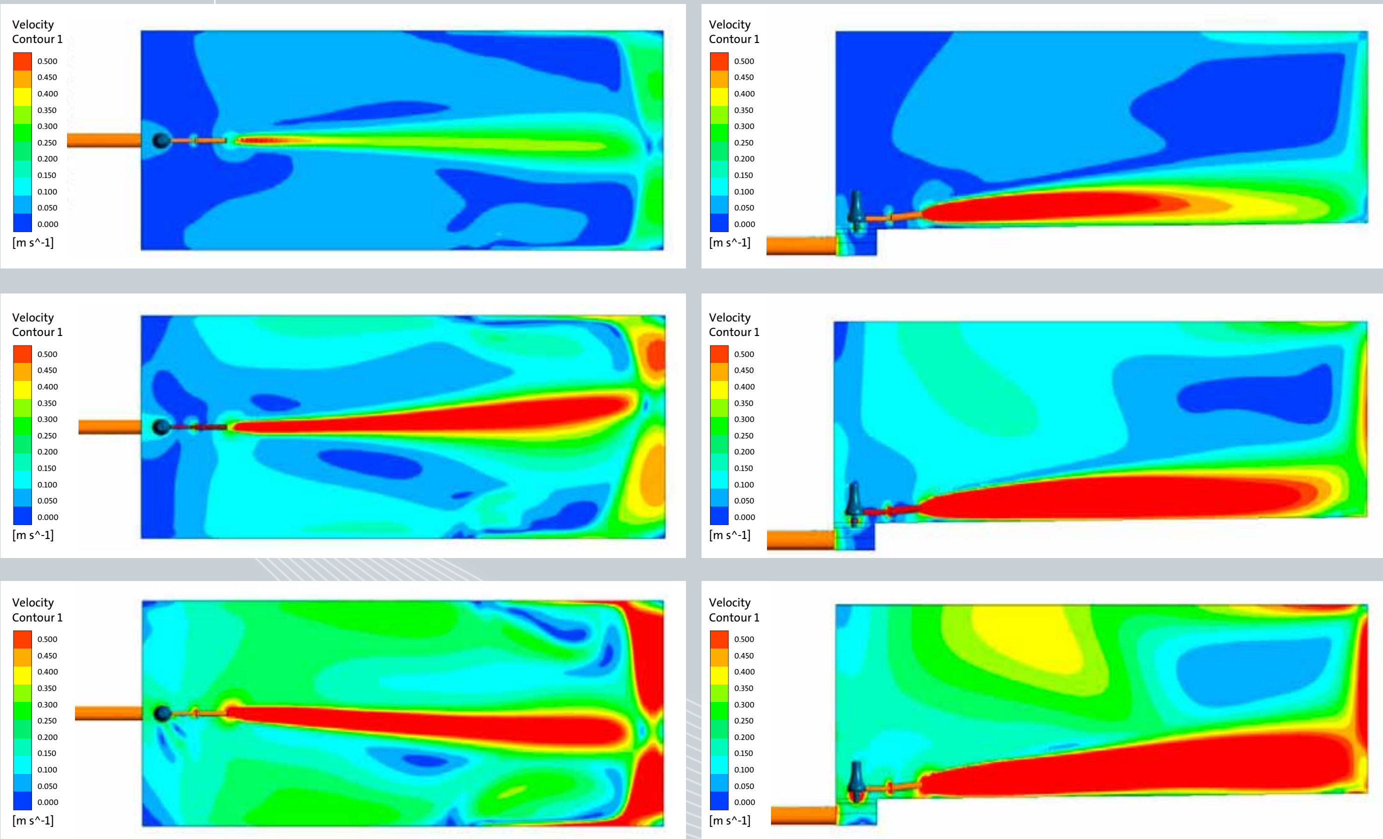
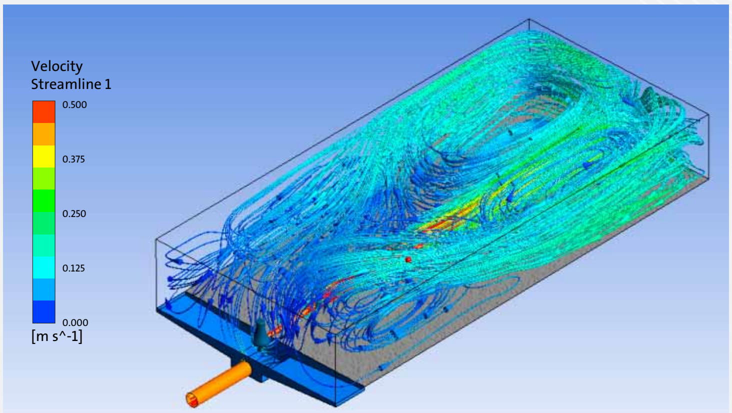


Figure 12:

Velocity contour plots showing what happens at different Flushjet capacities all other conditions are equal. From the top 25 l/s, 50 l/s and 75 l/s shown in a plane 0.15 m above the bottom plate (left) and in a plane through the Flushjet axis (right).



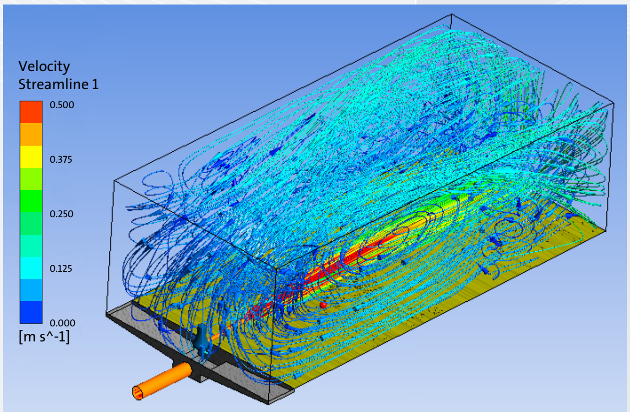


Figure 13:

Simulation of the difference in velocity streamlines, indicating mixing capabilities, at different water levels when using the same power input of the Flushjet.

stormwater tank will not concentrate so much that they exceed the solids handling limit of the outlet pump. Furthermore, when deciding the water level for complete mixing, it is also necessary to take into account that the Flushjet has enough time for resuspension of the settled matter in order to perform a perfect cleaning.

The simulation in Fig. 13 shows the difference in velocity streamlines and thus mixing capabilities at an equal power input of the Flushjet at different water levels in the stormwater tank. Based on the velocity streamlines, it can be seen that the Flushjet is not capable of mixing the entire volume of water at a water level of 4 meters, but as the water level drops to 2 meters the mixing capacity of the Flushjet will be more suitable to the stored volume of water.

For stormwater tanks, a given number of Flushjets will always be capable of providing the necessary thrust force to mix the complete volume of stored water. However this may entail that an excess cleaning efficiency is installed and mixers can instead be used to supplement the thrust together with an appropriate number of Flushjets.

Whether the Flushjet is used alone or in combination with a mixer will be a consideration made on the basis of e.g. length and volume of the tank, physical shape, and obstacles. Furthermore considerations should be given to the typical filling volume of water to be stored according to e.g. a duration curve (see Figure 26), in order to design a solution where the mixing capacity will not be oversized during most operational hours.

FACTS:

A mixer can only be operated when it is submerged and it has a higher thrust-to-power ratio than the Flushjet. When the water level drops to a certain level above the mixer, it might create a vortex which lowers performance and creates unbalanced conditions around the mixer.

The Flushjet on the other hand can work with great performance even when it is unsubmerged, as long as the suction pipe provides enough suction pressure to overcome the required Net Positive Suction Head (NPSH).

EMPTYING

Emptying the stormwater tank after the storm water runoff has ceased should be done at a pace that does not overload the sewer system and the downstream-situated wastewater treatment plant that it initially relieved. This can easily be controlled using variable-speed pumping, which is regulated based on measurements of the actual capacity of the sewer system to provide a near-constant and controlled flow to the sewer system.

If the flow to the sewer system does not have any hydraulic limitation when emptying the stormwater tank, emptying should not be done at a pace faster than is required for the cleaning equipment to have time to resuspend material and clean the tank. As the cleaning action of the Flushjet is not based on a single flush but on continuous flushing, an extra flush time/cycle can be used if desired. To do this the outflow pumps must be discontinued for a certain time, leaving an appropriate volume of water in the sump for final flushing. When this extra flush time is completed the outflow pump can once more be switched on, emptying the remaining volume of the detained water to the sewer system.

However the emptying time should also be performed at a pace so that the biological breakdown of organic matter does not create an odour issue due to formation of anaerobic zones in the tank. A balance between this and the above mentioned factors should be established.

PUMP DESIGN FOR EMPTYING THE TANK

Implicit in emptying (or filling) a stormwater tank is that huge variations in the hydraulic characteristics of the system will be experienced.

Controlling the outflow provides some challenges, as the hydraulic characteristics of the system change drastically during drainage, from large flow with low head to low flow with high head. Pumping with a duty point too far either to the left or right of the best efficiency point can result in reduced pump lifetime in addition to increased energy costs.

Due to this huge change in duty conditions during emptying specific demands are set when designing the outlet system of the stormwater tank and it should be secured that the duty point will not reach these extremes of the pump curve.

When system conditions result in an operating point exceeding the preferable operating range, this modifies the pressure acting on one of the sides of the impeller. This will result in unbalanced conditions, resulting in radial thrust which will deflect the pump shaft causing for example excessive load on the bearings, deflection of the mechanical seal and irregular wear on these parts.

If the duty point is too far to the left on the curve it can result in labile pump operation and excessive wear due to recirculation of abrasive particles in the pump because they cannot be removed from the system. If the duty point on the other hand is too far to the right on the curve it may cause cavitations due to an increase in NPSH.

Controlling the outflow can be done using variable speed controlled pumps or by gravity through motor valves, but in both cases the system curve for the application will vary as shown in Figure 14. Pumps and motor valves are normally controlled via flow measurements in the sewer system, so it will not be hydraulically overloaded during emptying of the tank.

When gravity cannot do the job, frequency controlled pumps can match smoothly the actual capacity of the sewer system during emptying (see Figure 15).

However, the design of the stormwater system might have certain constraints that must also be taken into consideration when draining the tank. For example, this could be desired emptying time or maximum and minimum flow.

FACTS:

Minimum velocity for riser pipe
To make sure that sand and similar materials can be pumped out of the tank through the riser pipe a minimum velocity, for example 1-1.5 m/s, must be maintained, depending on pipe configuration and particle characteristics. This velocity corresponds to a minimum flow that must be kept in the riser pipe.

Obeying the constraints put on the system provides some challenges when selecting pumps due to the great changes in hydraulic characteristics. Using the model and equations below, it is possible to estimate:

- Pump hydraulics based on required emptying time and maximum outflow
- Pump hydraulics based on required emptying time and minimum outflow
- Tank emptying time based on a specific pump curve

These estimations then show the specific required hydraulic performance for the pump, to make sure it stays within the acceptable duty area, even though large variations are encountered (see Figure 16).

Figure 14:

The great difference in hydraulic characteristics when emptying a stormwater tank is shown here.

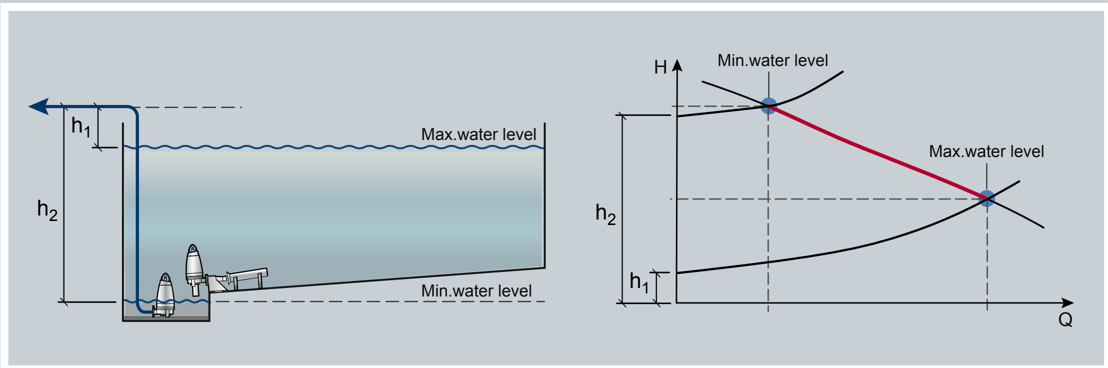
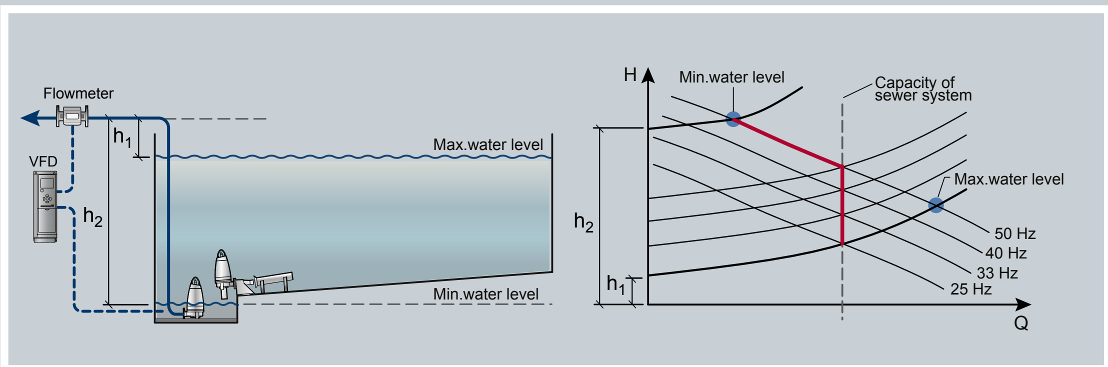
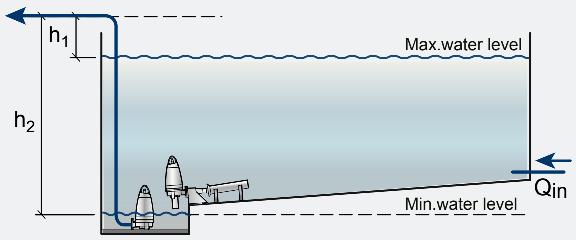


Figure 15:

The great difference in hydraulic characteristics when emptying a stormwater tank. To respect the capacity of the sewer system, the pump is being controlled by a frequency converter.





$h1$: highest water level
$h2$: lowest water level
Q_{max}: highest flow
Q_{min}: lowest flow
Q_{in}: inflow to the tank
ΔH_{max}: highest differential headloss
ΔH_{min}: lowest differential headloss
A: area of the tank
T: required time for emptying
K_v: pipe flow resistance
g: gravitational acceleration
ρ: density

Figure 16:

Schematic representation of the system defining how to calculate pump hydraulics and emptying time.

1) Pump hydraulics based on required emptying time and maximum outflow

Assuming the average flow can be calculated as the mean between the maximum and minimum flow:

$$\frac{Q_{min} + Q_{max}}{2} = A\frac{h_2 - h_1}{T}$$

The minimum flow can then be calculated as:

$$Q_{min} = 2A\frac{h_2 - h_1}{T} - Q_{max}$$

The two working points of the system are given by

$(Q_{max}, \Delta H_{max})$ and $(Q_{min}, \Delta H_{min})$

as illustrated in Figure 17.

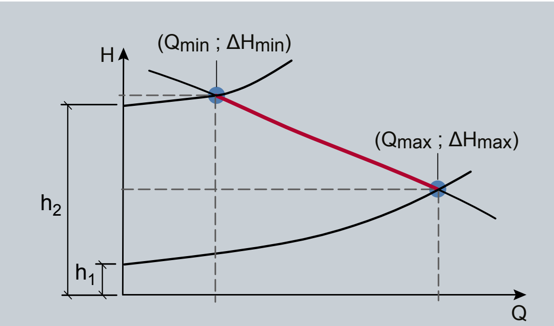


Figure 17:

Working points of a pump system. Note that with this notation $\Delta H_{max} < \Delta H_{min}$

The headloss (ΔH) of these working points can be calculated based on maximum and minimum flow from the following equations:

$$\Delta H_{max} = K_v Q_{max}{}^2 + \rho g h_1$$

$$\Delta H_{min} = K_v Q_{min}{}^2 + \rho g h_2$$

EXAMPLE:

Given an application with the following conditions:

T: 11 hours = 39,600 sec
h_1: 6 m
h_2: 0 m
Q_{max}: 0.1 m^3/s
Q_{in}: 0 m^3/s
A: 500 m²

The minimum flow reached during emptying within the given conditions is:

$$Q_{min} = 2 \times 500 \times \frac{6 - 0}{39{,}600} - 0.1 = 0.05\ m^3/s$$

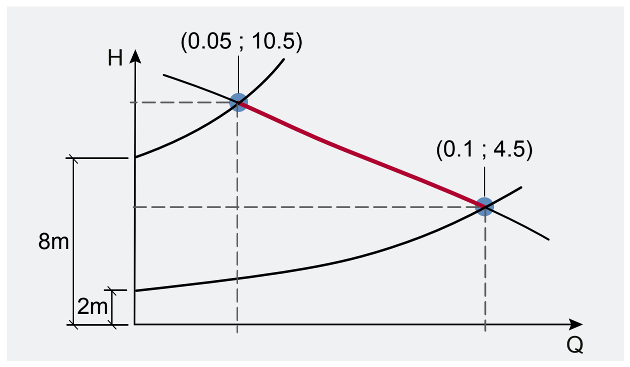
The minimum flow should then at least be 0.05 m^3/s. The two working points of the pump system can then be found when knowing:

ρ: 1000 kg/m^3
g: 9.82 m/s²

K_v: 2,455,000 kg/m⁷ at Q_{max}
K_v: 9,820,000 kg/m⁷ at Q_{min}

$$\Delta H_{max} = 2{,}455{,}000 \times 0.1^2 + 1000 \times 9.82(8 - 6) = 44{,}190 \text{ pa} \approx 4.5 \text{ mWC*}$$

$$\Delta H_{min} = 9{,}820{,}000 \times 0.05^2 + 1000 \times 9.82(8 - 0) = 103{,}190 \text{ pa} \approx 10.5 \text{ mWC*}$$



*)1 mWC = 9,806.95 Pa

2) Pump hydraulics based on required emptying time and minimum outflow

In contrary to the above, the minimum required flow can be a prerequisite together with the desired time for emptying. The maximum flow of the pump can then be calculated to keep the required time and, similar to the above, the two working points can be found based on the maximum and minimum flows.

$$Q_{max} = 2A\frac{h_2 - h_1}{T} - Q_{min}$$

3) Calculating emptying time based on specific pump curve

For a given pump or pump system it might be necessary to estimate the emptying time of the tank. This time can be calculated based on the maximum and minimum flow obtained from the pump operating points of the system by the following equation:

$$T = \frac{2A(h_2 - h_1)}{Q_{max} + Q_{min}}$$

EXAMPLE:
Given an application with the following conditions:

h_1: 6 m
h_2: 0 m
Q_{max}: 0.1 m³/s
Q_{min}: 0.05 m³/s
Q_{in}: 0 m³/s
A: 500 m²

The time for emptying will be:

$$T = 2 \times 500 \times \frac{0.1 - 0.05}{0.1^2 - 0.05^2}(6 - 0) = 40{,}000 \text{ sec} \approx 11 \text{ hours}$$

PHYSICAL DESIGN OF STORMWATER TANKS

The physical design of the stormwater tank is of utmost importance for obtaining trouble-free operation and is also important in regards to how efficiently it can be cleaned. When thinking about the physical design of the tank, it is not enough to consider only the dimensions, total volume of the tank and for existing tanks the remaining lifetime of the concrete structure. Just as important is the physical layout of the bottom plate and benches as well as including a properly designed sump and drainage channel, among others. An illustration defining technical terms in connection with the physical design of a stormwater tank is shown in Figure 18.

Below is an elaborated description of what is important when designing the physical structures of the tank.

FORM AND SHAPE

For the purpose of storm water detention, both new and existing tanks can be used. New tanks can be constructed specifically for the purpose whereas existing tanks with a little effort can be rebuilt to meet the layout requirements.

The form and shape of the tank does not limit the usability for storm water detention, meaning square, rectangular or round tanks and other forms and shapes can be used for the purpose. This gives the flexibility to use existing tanks or fit in new tanks wherever space is available.

Rebuilding existing tanks might provide some challenges. Besides estimating the remaining lifetime and the specific layout of the construction, the buoyancy of the tank must also be taken into consideration. This should be considered, as the up force on an empty tank can be so powerful that it might collapse or float. Coping with this can be handled in different ways: by permanently lowering the water table, increasing the ballast of the tank or incorporating gate valves into the tank, which lets in water if the water table rises.

BOTTOM PLATE

Design of the stormwater tank bottom plate is a critical parameter for an efficient removal of solids from the tank. For automatic cleaning with a Flushjet, the bottom plate should have a slope of around 1-4 % towards the tank outlet. In addition to the slope, the texture of the bottom plate is also important. The plate should be smoothened to minimise roughness and avoid local depressions in the plate where water preferentially will run and form stream channels or impose additional flow resistance.

The determining factor for moving solids deposited at the bottom plate to the outlet during step 3 and 4 in the cleaning phase is the shear stress (τ). The shear stress is the force acting between the flow of water and the deposited material which can be calculated as:

$$\tau = \gamma \times R \times I$$

τ: Shear stress (N/m2)

γ: Specific weight of water (N/m3)

R: Hydraulic radius (m)

I: Bottom plate slope (m/m)

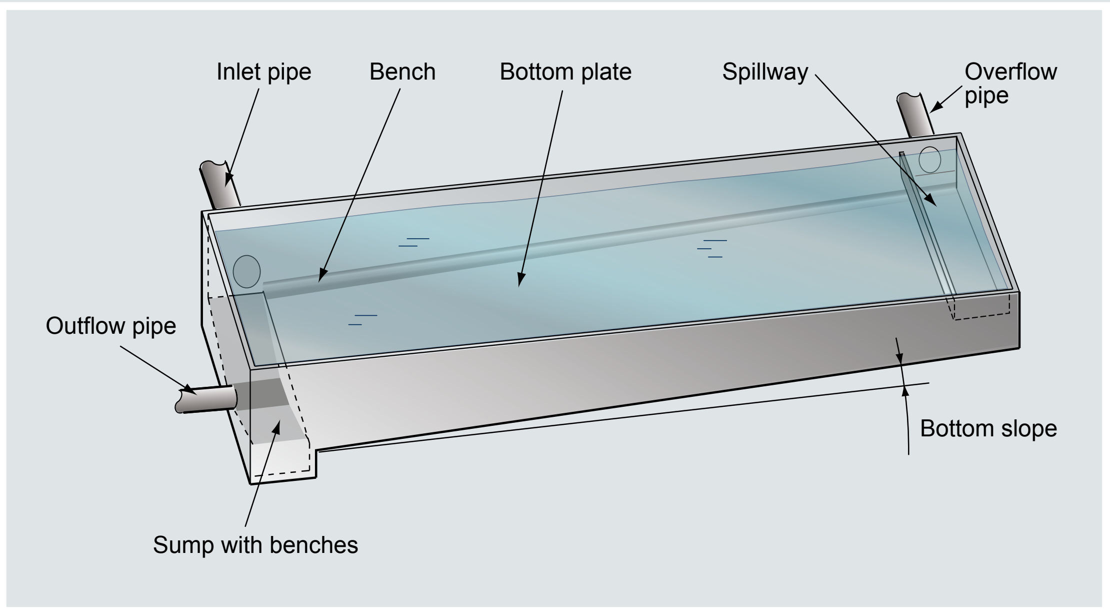


Figure 18:

The terms used in connection with the physical design of an open rectangular stormwater tank

The shear stress needed to obtain self cleaning can vary significantly depending on what kind of material is contained in the storm water. This is in regard to size, weight and texture where greasy, and heavy material consisting of large particles requires a higher τ to obtain self cleaning. In stormwater sewers a τ of 2-4 N/m^2 is normally considered sufficient for obtaining self cleaning and used as dimensioning criteria. This is therefore also seen as a guide for the bottom plate of a stormwater tank during final emptying.

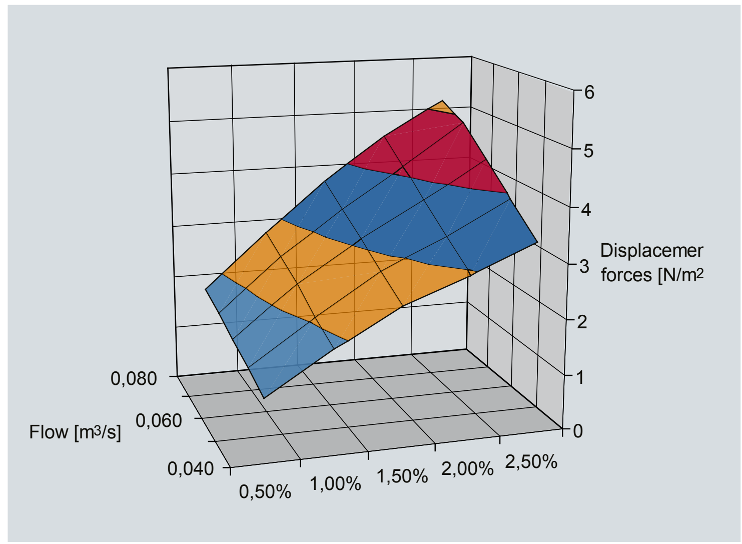


Figure 19:

Bottom displacement forces as a function of slope and flow. The simple spreadsheet model used to construct the graph assumes that the water flowing from the back wall of the tank and back to the sump is equally distributed over the entire cross section of the tank. The model does not take into account that parts of the cross section is taken up by the water jet generated from the Flushjet, which flows in the opposite direction.

For stormwater tanks with relatively low water depth, the hydraulic radius can be considered to be equal to the natural depth of water over the bottom plate. This depth can be estimated from the Manning equation based on the surface roughness, bottom slope and water flow from the Flushjet.

Visualised by a simple spreadsheet model increasing either the water flow through the Flushjet and thereby the hydraulic radius or the bottom slope will result in increasing displacement forces, ensuring that the tank will be self-cleaning.

However, increasing these two parameters infinitely is not practical or economical in relation to power consumption for example and may induce undesirable side effects that minimise cleaning efficiency.

The CFD simulations in Figure 20 illustrate how the effective jet length of the Flushjet is directly influenced by the slope of the bottom plate. From the flow velocity profile it can be observed that the jet length in a tank with a bottom plate slope of 1% has a better reach compared to a slope of 8% at equal Flushjet performance.

Furthermore it can also be seen that at a slope of 8% and a Flushjet performance of 50 l/s the water jet partly terminates prior to reaching the back wall as it hits the bottom of the tank. At the interception with the bottom plate the water jet looses energy. This interception reduces the cleaning and mixing action of the jet which also is evident when comparing the velocity contours at the simulations.

Increasing Flushjet performance to 75 l/s ensures that the water jet reaches the back wall even at a slope of 8%. However the water jet has reduced power for mixing and cleaning as some of the energy is lost at the bottom plate which is evident from the velocity contour plots when comparing the two simulations with different slopes and Flushjet performance of 75 l/s.

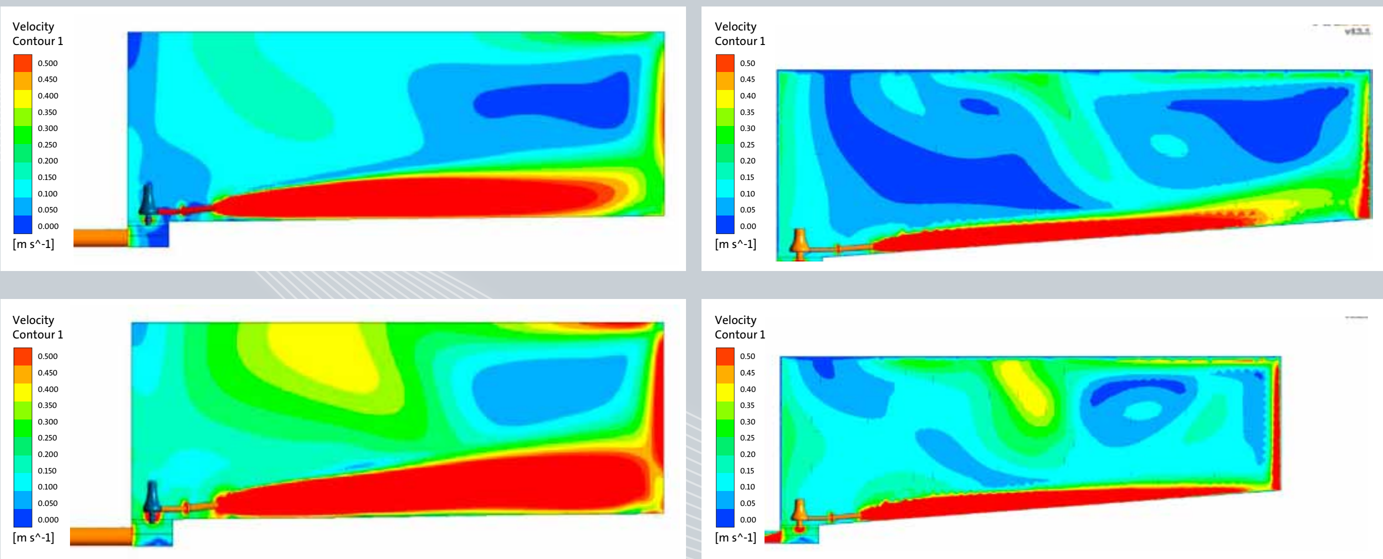


Figure 20:

The bottom slope directly influences the jet length of the Flushjet, where an increasing bottom slope decreases the effective jet length. Left: tanks with slope of 1%. Right: tanks with slope of 8%. Top: Flushjet performance of 50 l/s. Bottom: Flushjet performance 75 l/s. All other conditions are equal.

The actual slope of the tank will in practise be determined by several factors which together ensure that the desired displacement force is met. These factors are:

- Ensuring that the tank is dug as deep as is feasible
- Selection of the Flushjet with the lowest possible power consumption to deliver the required jet length and flow
- The fact that the effective jet length of the Flushjet is inversely related to the slope of the bottom plate, with regards to having sufficient fall towards the sump, so water and material will be transported in this direction.

BENCHES

To avoid accumulation of solids in for example the corners of the tank, flow patterns with least possible hydraulic losses should be established to minimise required power consumption of the cleaning equipment. When water flows over a surface the velocity will decrease the closer the distance to the surface is due to the friction losses exhibited by the texture of the surface (Figure 21).

In corners or where the tank walls and bottom meet, two surfaces are in close proximity, and this will decrease the velocity significantly due to the friction losses from both of these surfaces. The low velocity in this area will favour sedimentation of material. Of course, applying excessive power could well maintain a high velocity; however this cannot be justified economically. Slanting benches could be made to minimise the effect of friction losses in these areas (Figure 22), and increasing power input ought not to be considered. These benches can either be made in the corner or as benches running along the entire side of the tank.

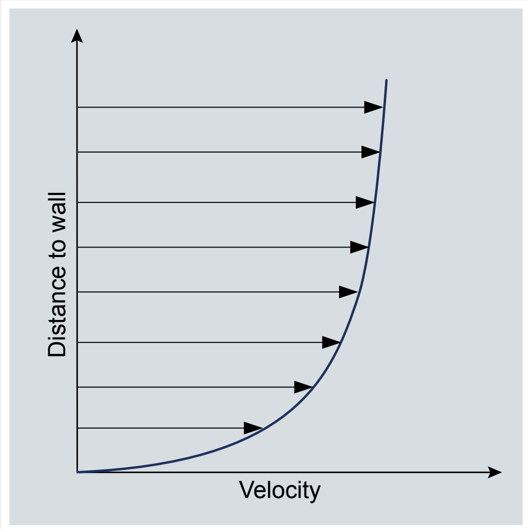


Figure 21:

Velocity profile of a liquid flowing over a surface.

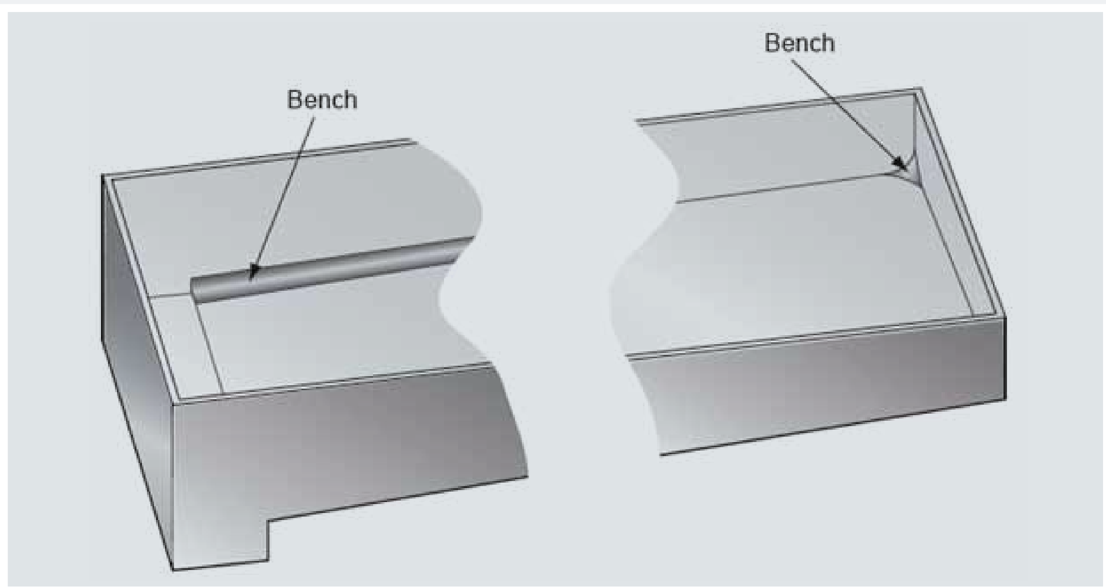


Figure 22:

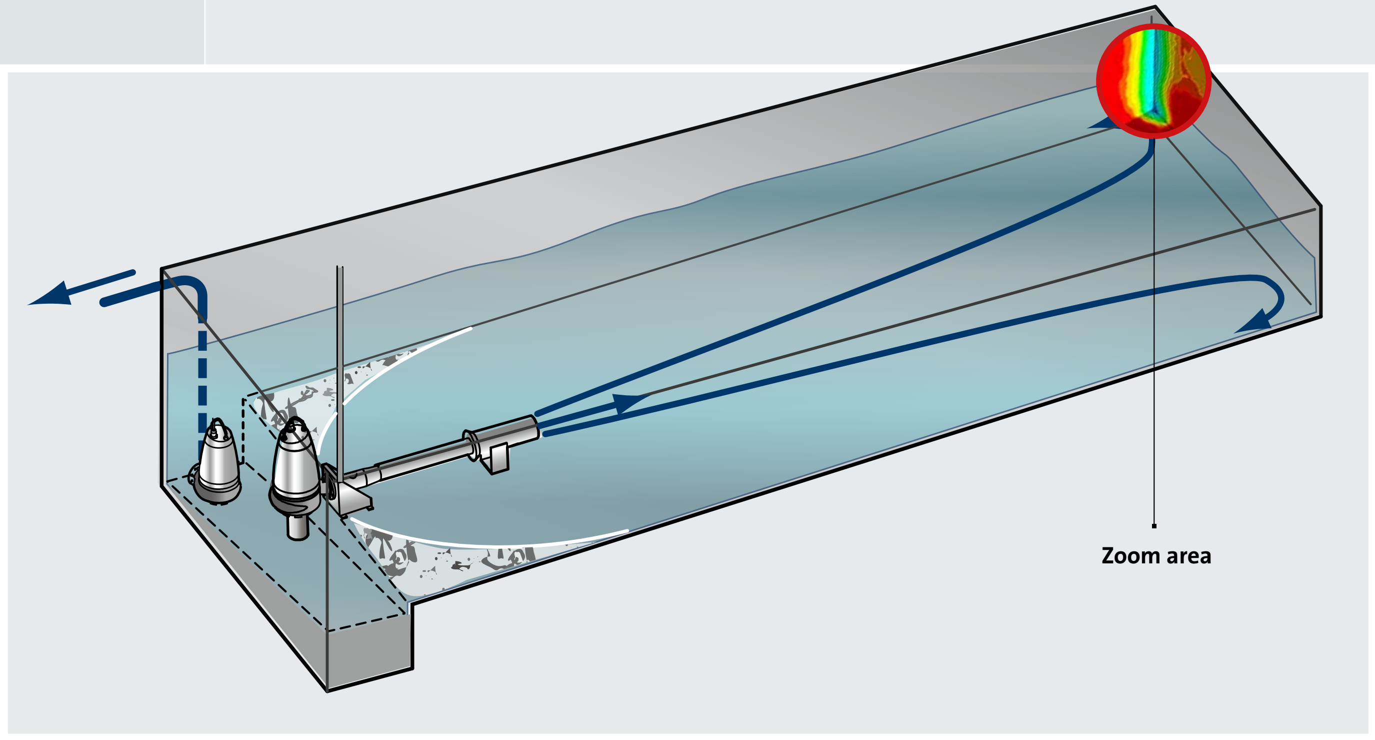
Benches in a stormwater tank to minimise friction losses at corners and to mimic natural flow patterns.

Left: benches running along both sides of the tank in the entire longitudinal direction.
Right: bench at the corner at the wall furthest away from the Flushjet.

The effect on wall shear stress in the stormwater tank when using benches has been simulated. Velocity contour plots showing a corner of the stormwater tank are presented in Figure 23 in situations both with and without a bench.

As can be seen the corner bench and the side bench will exhibit more or less the same effect close to the back wall of the tank where the low shear stress in the corner is eliminated. The remaining part of the side bench will first give maximum benefit during step 3 and 4 of the cleaning phase when the water level is low.

In this situation a similar effect will be seen as with the corner, where areas with low shear stress are eliminated, due to the slanting benches.



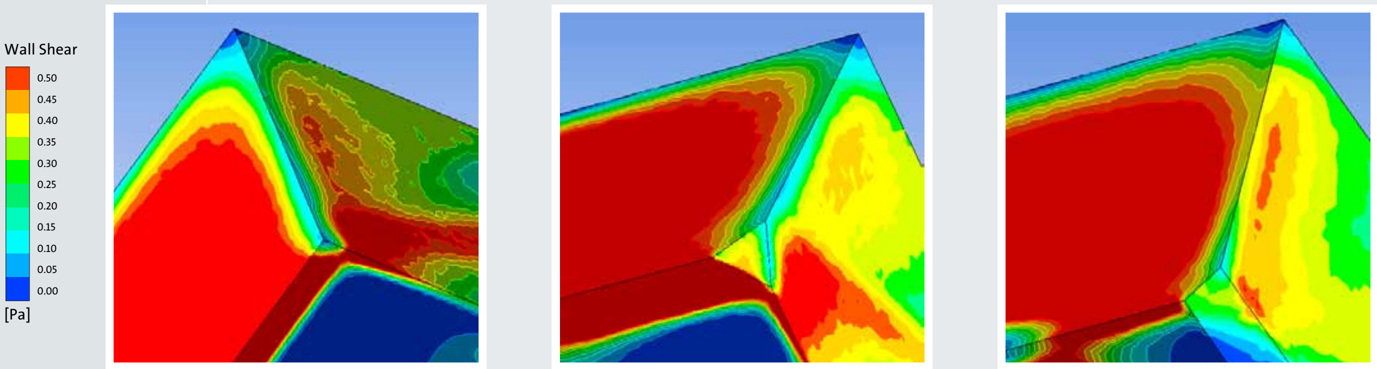


Figure 23:

Shear stress contour plots to show differences in wall shear stress when using benches in a stormwater tank. Simulations are made at high water level under steady state conditions and an increase in shear stress will be expected as water level drops during the depletion period.

Simulations show a zoom on one of the corners furthest away from the Flushjet.

From the left: tank without benches; tank with bench in the corner; tank with bench running along the side.

DIMENSIONS

Area

Basically, the physical area of a tank, whether new or old, does not limit the applicability for storm water detention and implementation of a subsequent hygienic cleaning. However it is not only the specific tank area that must be taken into account when deciding which equipment to install in the tank, the length/width ratio is even more important and basically determines which type of Flushjet to install. In Figure 24 a Flushjet capable of cleaning 78 m2 has been installed in a tank of equal area in two different positions.

In the first position the length/width ratio of the tank suits the water jet generated from the Flushjet through all phases of stormwater tank operation; from mixing to the final cleaning phase. In the first case almost all of the energy in the jet stream will be utilised for mixing and cleaning, and subsequently the jet will be able to spread all the way to the side walls during final cleaning. In the second position, where the Flushjet is placed on the longest side, most of the power in the water jet is lost on the tank wall which means that less power will be available for mixing and cleaning. Furthermore, when the water level is at the end of the depletion period the water jet will not be able to spread all the way to the corners, leaving settled material at the side of the tank.

	LENGTH/ WIDTH RATIO	EJECTOR TYPE
FLUSHJET WA	~ 3	WATER/AIR
FLUSHJET WW	~ 2	WATER/WATER

The length/width ratio of the Flushjet changes depending on the actual bottom slope. At a slope of around 1 % the Flushjets have the following specific length/width ratios of their water jets.

When constructing new tanks specifically for the purpose of storm water detention, it is therefore advantageous already in the design phase to consider what type of Flushjet is intended for keeping the tank clean so the tank area can be designed in a specific length/width ratio.

Depth

The depth of the tank is chosen based on the height differences in the catchment area and the actual depth of the sewer system. This height difference sets the basis for tank layout as there is a limit for the maximal acceptable back water level in the system. This results in either a shallow self-emptying tank being used or, as used in most instances, a deeper tank, where emptying must be done by pumps.

Besides the height differences, available space (foot print) also helps the decision whether to build shallow tanks over large areas or deep tanks that do not claim much land. However, building deep might be expensive due to a high groundwater level, for example, so the final design will be a compromise between actual conditions on site, minimum required slope and maximum available foot print.

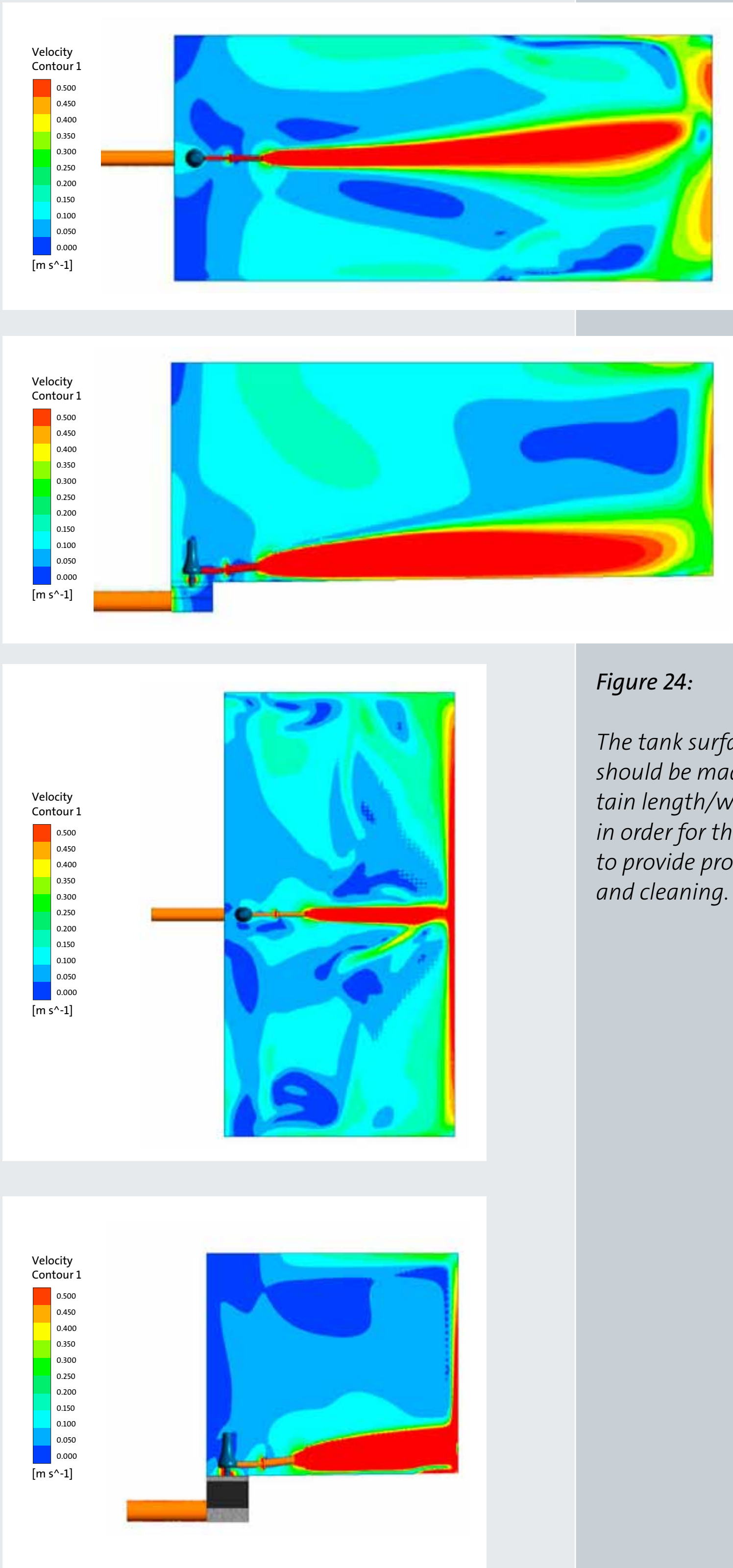


Figure 24:

The tank surface area should be made in a certain length/width ratio in order for the Flushjet to provide proper mixing and cleaning.

STORAGE VOLUME

Dimensioning a stormwater tank consists of establishing the storage volume that will ensure a desired equalisation in the runoff based on a given maximum overload criterion.

To make this calculation, the system can be simplified by only taking the inflow (Q_{in}) and outflow (Q_{out}) that corresponds to the storm water runoff flow. For a combined sewer system, the dry weather flow is therefore not a part of the calculation.

The continuity equation for a tank during filling or emptying is described by:

$$Q_{in} - Q_{out} = \frac{dV}{dt} = A \times \frac{dh}{dt}$$

Where V is the volume, A is the area and h is the water level in the tank. By integration of the continuity equation the storage volume can be found as:

$$V = \int_{h_{min}}^{h_{max}} A \times dh = \int_{0}^{t_1} (Q_{in} - Q_{out})\, dt$$

Where h_{min} is the minimum water level, h_{max} is the maximum water level and t_1 is the filling time.

The needed storage volume for a certain in- and outflow to the tank can be graphically shown as in Figure 25.

When designing a tank, Q_{in} must be chosen based on the stormwater event that will give maximum volume for a predefined overload criterion. This can be based on the overload frequency or repetition period. Q_{out} on the other hand can be determined freely but it is desirable that it is as constant as possible to avoid overload of the sewer system when the water is guided back.

As actual data for stormwater events in an exact area is seldom available, the stormwater events used for dimensioning the storage volume are based on validated constructed data or historical stormwater events. These data contain information about intensity, volume, duration, frequency, etc., that can be used to estimate the storage volume.

Visualising the stormwater events on a duration curve or by similar representation can help to estimate the necessary or cost-effective storage volume that will ensure that the predefined number of overloads from the tank is not exceeded. From the curve can be read how large the volume of the tank should be to be able to store the water from, for example, 90% of all stormwater events, or for events having a volume equal to or bigger than a defined value. The duration curve can furthermore be used to estimate whether it will be beneficial to split up the storage volume of the tank into several sub volumes. This could be useful to consider if the tank only becomes partly filled during most stormwater events as it will only be necessary to clean a section of the tank and not the whole tank.

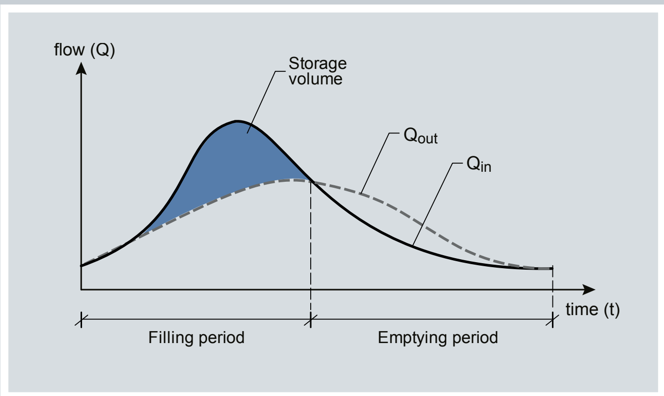


Figure 25:

Inflow hydrograph illustrating how to estimate the necessary storage volume based on inflow and outflow of the stormwater tank or upstream a flow split device.

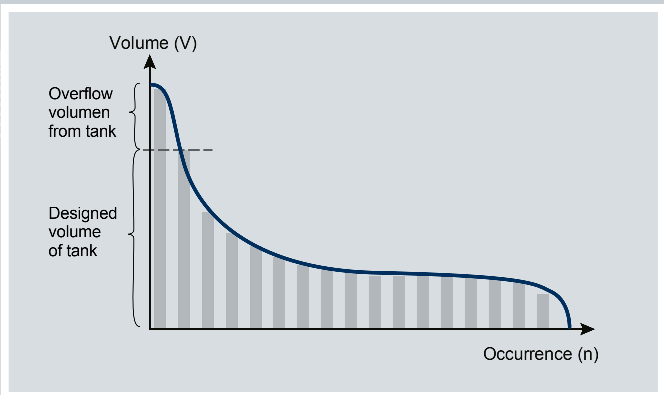


Figure 26:

Graph used for estimating for example the needed storage volume of a stormwater tank, the number of compartments needed to minimise cleaning, or the number of expected overflows based on a certain tank size. Occurrence is defined as the number of events that give rise to a water volume equal to or bigger than a certain volume, divided by the total number of events.

INLET

Guiding storm water into the stormwater tank can, depending on the placement of the tank, be handled either by gravity or by using pumps. The inlet should be constructed with backflow protection to avoid the stormwater tank putting an unintended hydraulic load on the system that the tank is in fact designed to relieve.

For off-line detention, the inlet structure can be designed as a weir overflow that functions only when a predetermined flow in the sewer is exceeded (Fig. 27). The overflow can then be guided from the overflow structure to the stormwater tank by gravity or using pumps.

For in-line detention, throttling in response to difference in pipe dimensions between inlet and outlet pipes will ensure that water will backup in the stormwater tank (Fig. 28). Here, gravity can normally be used to convey water both in and out of the tank. In-line detention requires that the backwater level does not exceed the lowest points in the system it relieves, if flooding of upstream areas is to be avoided.

When guiding water to the stormwater tank, the inflow must fulfil what may appear to be conflicting tasks. The inflow should be as fast as possible to relieve the hydraulic load of the sewer system; and yet the momentum of the inflow should be limited to avoid that material in the tank is in suspension.

During the filling period, sedimentation of organic matter is desired due to the risk of overflow, and turbulence in the tank should therefore be minimised. The only hydraulic disturbance in the tank during filling will be the inflow jet. Dissipating the momentum in the inflow jet will decrease the turbulence, enhancing the settling of material in the tank. Slowing down the inflow jet can be done using a weir overflow, a baffle, or other similar arrangements.

GRIT AND STONE CHAMBER

The significant amount of water that arrives at the stormwater tank during rainfalls is powerful enough to drag large concrete chunks or other large obstacles with it. Having these objects scattered on the tank floor will reduce cleaning efficiency as well as damage the installed equipment. In some cases, the inflow can then be guided through a separate reservoir where grit, stones, litter and other large objects can be captured, preventing this problem (Fig. 29). This reservoir must be constructed in a way that ensures organic matter does not settle but is dragged into the stormwater tank, to avoid odours from the chamber.

Independent of chamber design, an access must be constructed in order to empty the chamber for the trapped material at regular intervals and for service inspections.

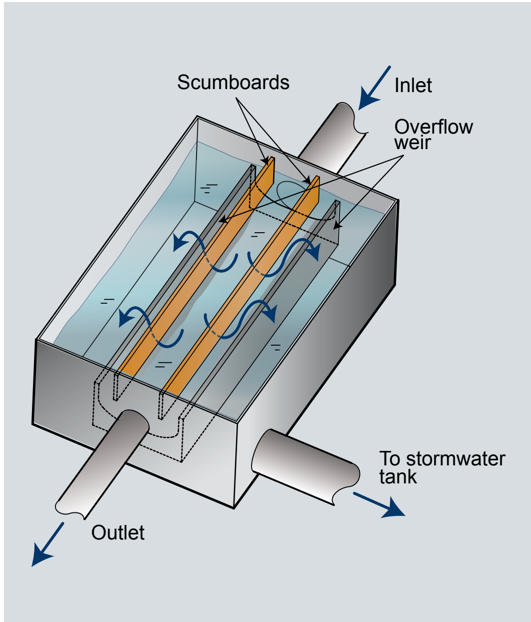


Figure 27:

An example of a flow split structure where water at a flow exceeding the outlet flow will be diverted into the stormwater tank for temporary storage. The flow split structure can be designed with or without scumboards.

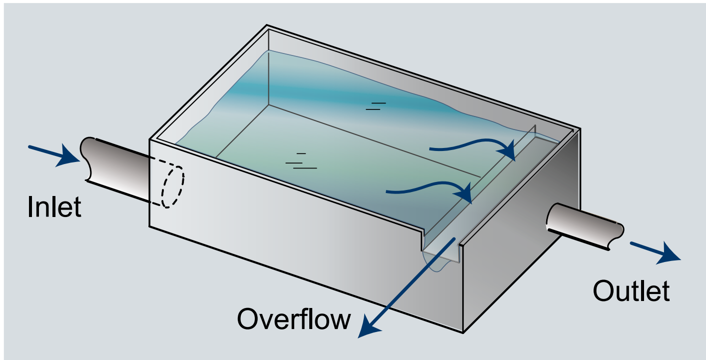


Figure 28:

An example of throttling in an in-line detention, where the inlet pipe has a bigger diameter than the outlet pipe. When the capacity of the outlet is exceeded water will accumulate in the stormwater tank.

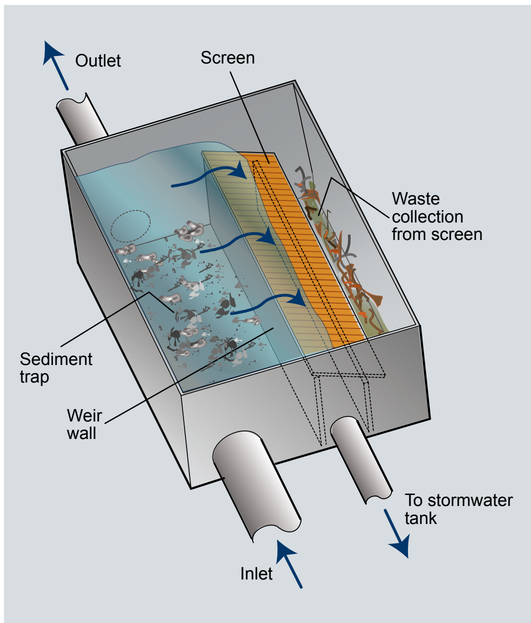


Figure 29:

A grit and stone chamber can be integrated in the sewer system before the stormwater tank in order to trap large contaminants instead of letting them enter into the stormwater tank.

OUTLET

From the stormwater tank there must be at least two outlets; a *controlled* outlet and an *emergency* outlet.

When storm water inflow ceases and the emptying period is initiated, the stored water should be guided back to the sewer system where it is conveyed to the treatment plant. This must be done in a manner to ensure the sewer system is not overloaded. Using a controlled outlet provides the opportunity to control and regulate the emptying of the stored water in consideration of the actual load and capacity of the sewer system. In advanced control systems, where wastewater flows in citywide systems are optimised continuously, other parameters such as the water levels in other storage tanks can decide the outflow pumping operation of the specific tank. Using pumps for a coordinated control of the sewer system thereby enables that advanced control strategies can be used to optimise and manage wastewater flows in the entire system. However the outflow capacity and pipe dimension should still be designed and constructed so the outlet structure is capable of guiding suspended solids out of the tank without settling and thus blocking the outlet.

Moreover, the use of pumps or motor valves gives the opportunity to refine cleaning of the tank by reducing the outflow. This reduction should normally be done in the last period of the cleaning process at low water level. Setting the actual volume of water during flow reduction must be done in relation to the total storage volume. The volume left during cleaning must be negligible compared to the total volume in order to cope with any possible stormwater event that can take place during this process.

By a careful control of the outlet, the Flushjet works as a continuous flush cleaning system that can be tuned to the actual conditions and demands compared to single flush systems. This gives an opportunity to run an optimal cleaning process where the exact energy needed to obtain complete cleaning is matched specifically. This is obtained through a predefined cleaning time calibrated according to the actual demands.

If the outlet flows uncontrolled from the tank through an outlet pipe, a flow regulator device is often incorporated to work as a brake for the capacity. However this will not adjust precisely to the actual capacity of the sewer system but in some cases serve the purpose (see Figure 30).

EMERGENCY OUTLET

Sending untreated wastewater to the recipient is not desirable. The stormwater tank's function is to accumulate polluting material and reduce the number of overflows from the tank. It is however not economically feasible to construct stormwater tanks that are large enough to cope with all stormwater events and an evaluation based on the water quality goals of the recipient. The risk for overflows from a tank with a certain storage volume is based on statistical data for 10, 50 or 100 year storm events as well as the duration curves.

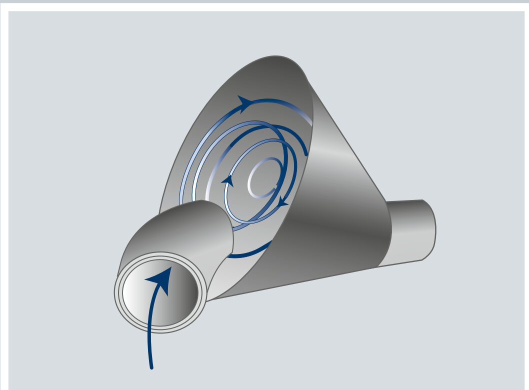
The storm water in excess of the storage volume needs to be directed safely and in a controlled manner out of the tank, instead of causing a hydraulic overload of the sewer system. The stormwater tank must therefore be equipped with an overflow arrangement, such as a spillway or a pump, which can at least discharge an amount corresponding to the maximal inflow to the tank (Fig. 6).

Positioning of the overflow arrangement should be done so that a short cut from the inlet to the emergency outlet is avoided. This can be done by placing them far a part from each other, with hydraulic streamlines taken into considerations. Where possible, the inlet and emergency outlet should be placed in different sections of the tank.

During the filling of the tank, the intention is that suspended solids settle at the bottom of the tank. When using pumps to cope with the overflow, it is therefore not advisable to pump from the bottom of the tank, as large amounts of settled matter will be flushed out to the recipient, and this is to be avoided. Instead, pumps with large flows and most often low heads should be installed to pump from the uppermost volume of the stored water.

Figure 30:

A water brake can dissipate the outflow momentum. The water flow is guided tangentially into the volute of the hydro brake where a vortex will form. The resulting high peripheral velocities will create an air-filled core which will result in increased back pressure that reduces the discharge flow to the designed maximum limit.



When using spillways or overflow weirs, floatables and other suspended pollutants will be washed to the recipient. To minimise this pollution, the overflow arrangement should be equipped with a skimmer and/or a screen (Fig. 31). Screens can be installed either vertically or horizontally, with or without build-in skimmers. Depending on the design of the emergency outlet, one type may be preferred over another. Independent of installation, the material captured on the screen must be automatically returned to the detained water in the tank with which it will be conveyed to the wastewater treatment plant. This is to minimise the need for service of the tank.

Depending on the water quality goal for the receiving water, other arrangements, such as flow regulators to minimise erosion of the recipient or equipment for disinfection, must also be considered at the emergency outlet.

When the water in the tank reaches a level where it spills over the overflow weir, a backwater effect in the tank will occur. This level, h, can be estimated by the following equation based on the water flow, Q, and width of the weir, B. The coefficient C is specific for the dimension and design of the weir and must be chosen accordingly in some cases it must be determined experimentally.

$$Q = C \times B \times h \times \sqrt{2 \times g \times h}$$

The expected backwater level should be estimated and it must be taken into account when placing the overflow arrangements in order not have water spilling over the sides of the tank. This means that the tank walls must be higher than the maximum water level, thus a certain volume of the tank cannot be used for storage. In addition to this backwater level a certain safety margin is also included when placing the weir, making the storage volume even less as the difference between weir and edge of the tank is increased.

To utilise the entire volume of the tank, tip-weirs can be installed. This will make it possible for the water to backup to the top of the tank, thus giving additional time for settling of material, before an eventual overflow occurs (Fig. 32).

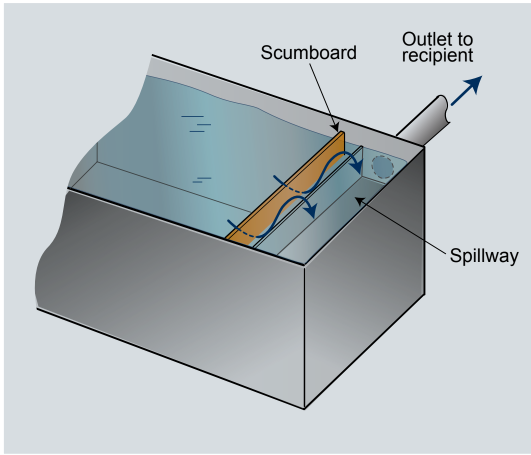


Figure 31:

Examples of a skimmer arrangement that will detain most floatable material in the stormwater tank.

SUMP AND RUNOFF CHANNEL

The sump and runoff channel must be constructed in a way so the detained water with suspended solids is conveyed to the outlet pump or gravity outlet independent of outlet capacity. It is important that the sump contains an edge/weir that the sand can fall over. This will prevent sand accumulating at the bottom plate around the outlet and behind the cleaning equipment.

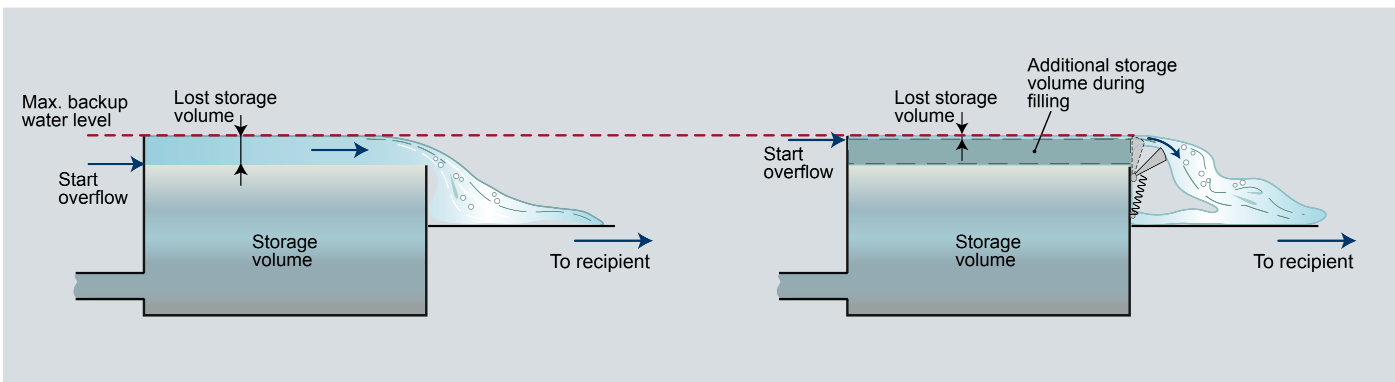
The sump can furthermore increase operation time of the Flushjet and hence cleaning time. This can be done if the Flushjet is equipped with a water inlet pipe that draws in water from the sump in a level below the bottom plate figure 33.

If the Flushjet does not have a water inlet pipe and must be stopped before the water level is below the bottom plate, some of the suspended material in the remaining water will have time for settling at the bottom of the tank (Figure 33 left).

As the slope of the tank for practical and economical reasons is not steep enough, the passive gravity water flow cannot drag the settled material to the sump which means that the tank will not be cleaned completely.

Figure 32:

Sketch showing the additional storage volume gained with a tip-weir installed at the emergency outlet in contrary to having a weir overflow.



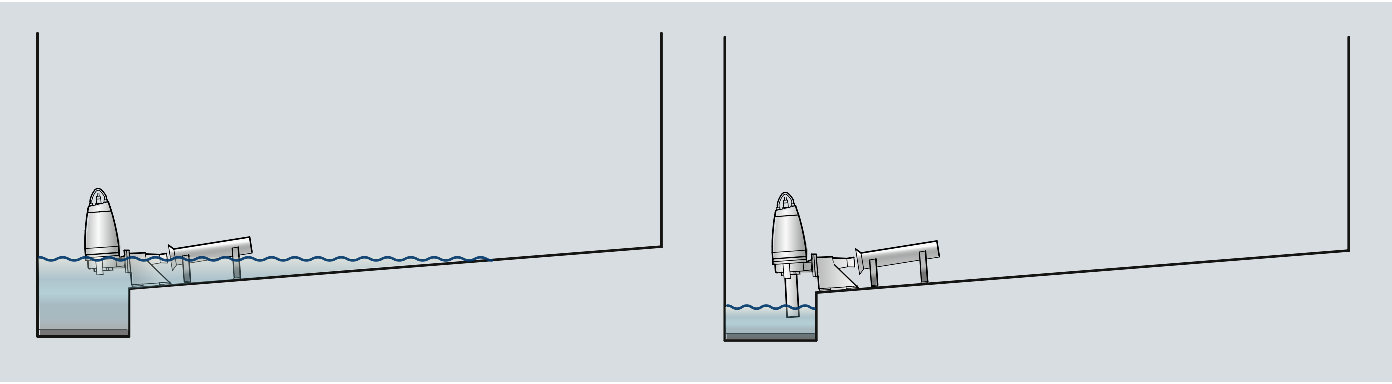


Figure 33:

The effect of having an inlet water pipe on the pump is that cleaning can proceed until the tank is practically empty so the entire bottom plate can be completely cleaned.

However, if the Flushjet is able to flush until the water level has dropped below the bottom plate, it will first stop when the remaining water is present in the sump (Figure 33 right). The limited volume of water left in the sump will give a relatively short detention time, limiting the time for settling of materials. Together with the slope of the sump, this will ensure that all suspended materials are conveyed back to the sewer system.

The sump can be positioned in different ways in the tank. For rectangular tanks it is often placed at one end of the tank walls or traversing the tank at the middle. For circular tanks it can be positioned at a tank wall or at the centre of the tank (Fig. 34).

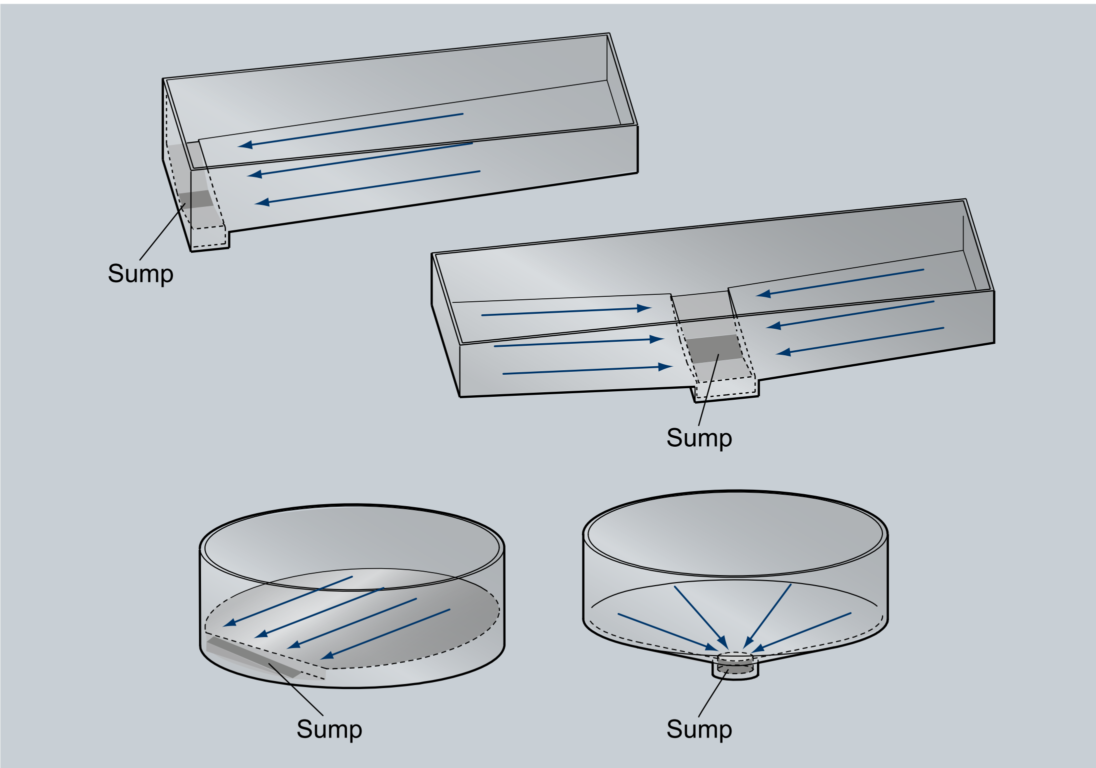
Independent of sump layout, effective removal of material in the runoff channel is best obtained if benches are constructed to mimic hydrodynamic flow patterns, thus reducing areas where sedimentation can take place and helping to guide water to the outlet. It is furthermore important that the benches are constructed so they have a clearance height up to the bottom plate (Figure 35). This will allow solids that are dragged to the sump to fall into the runoff channel and get flushed away. Without this clearance height solids might be flushed back up on the bottom plate and deposit at the walls behind the Flushjet.

The actual tank shape and positioning of the sump provides the basis for how cleaning equipment should be installed for efficient cleaning. Choosing one or the other positioning of the sump in a certain tank shape depends, among other things, on the desired accessibility of equipment and piping, construction costs and maximal depth of construction.

Another important issue when designing the sump is the fact that there must be space reserved for the installation of equipment such as Flushjets, a com-

Figure 34:

Sump positioning in different tank shapes. Left: wall placed sump in a rectangular and circular tank. Right: traversing sump in a rectangular tank and centre sump in a circular tank.



mon pump to feed several ejectors, or outlet pumps if these are necessary. By installing equipment in the runoff channel, the amount of equipment installed at the bottom plate is minimised and this means far less additional flow resistance and fewer places for unwanted sedimentation.

Installation of equipment in the sump should be done in a way so suspended solids carried to the sump do not accumulate and block the outlet. This requires that the distance between individual pumps as well as pumps and walls should be at least equal to the free passage of the pump. However, larger impurities might be dragged into the tank depending on upstream measurements, which should also be taken into account during positioning.

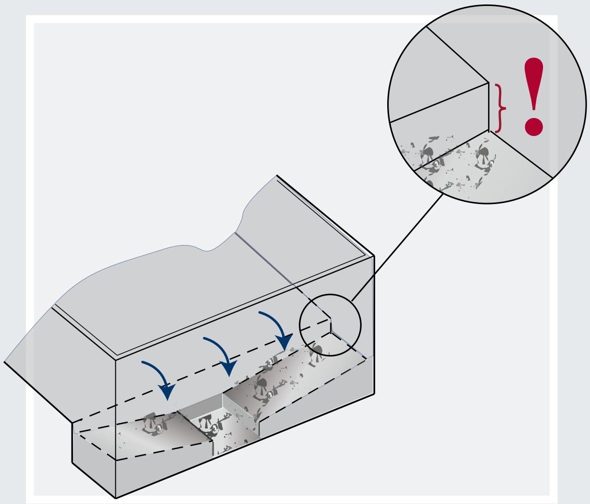


Figure 35:

Slanting benches in a wall placed runoff channel. Note that the benches start below the bottom plate so the material in the tank can fall into the sump and get flushed away.

SELF CLEANING OF THE RUNOFF CHANNEL

As no actual flushing by the Flushjet takes place in the runoff channel it can be compared to a sewer pipe, and therefore it must be designed to be self cleaning. This ensures that all material dragged down from the bottom plate will be conveyed to the pump sump or gravity outlet and removed from the stormwater tank.

Self cleaning of sewers is often linked to water velocity and for pipes in sewer systems self cleaning is obtained with a water velocity above 0.8 m/s. Thus keeping this velocity as a minimum in the runoff channel of the stormwater tank will ensure that detained material is conveyed away from the sump.

Water speed is not a completely reliable measure for the ability of water to carry material, as the mean speed for different cross sections and diameters will give different carrying abilities. On the other hand, self cleaning of the runoff channel can be expressed as the shear stress (τ) acting at the bottom surface as explained above (see paragraph about bottom plates on page 17).

To illustrate how the outlet flow influences the self-cleaning ability during final cleaning, simulations varying this parameter have been made. The simulations show the bottom shear stress in the runoff channel which is emptied by gravity through an outlet pipe. However the same would be the case if a pump has been used for the purpose.

Increasing the outlet flow will yield a higher bottom shear stress in the runoff channel as expected. The magnitude of the outlet flow needed to obtain the necessary shear stress in the sump depends among other things on the slope. This therefore implies that the slope and outlet flow somehow should be harmonised to ensure an efficient cleaning. The Flushjet will furthermore recirculate a lot of water during the emptying period, which also will aid in flushing the sump.

At a small outlet flow there will be a risk that matters collected in the sump will build up and ultimately block the outflow pipe due to a too low shear stress in the channel. Therefore it is crucial to design the sump with a high enough outlet flow to make sure that matters collected in the sump are effectively conveyed to the sewer system through the outlet pipe or pump.

Also during final cleaning, when the water falls from the bottom plate and into the sump, the self cleaning will be enhanced as the turbulence created by this action will keep material in suspension in the water while it flows to the outlet.

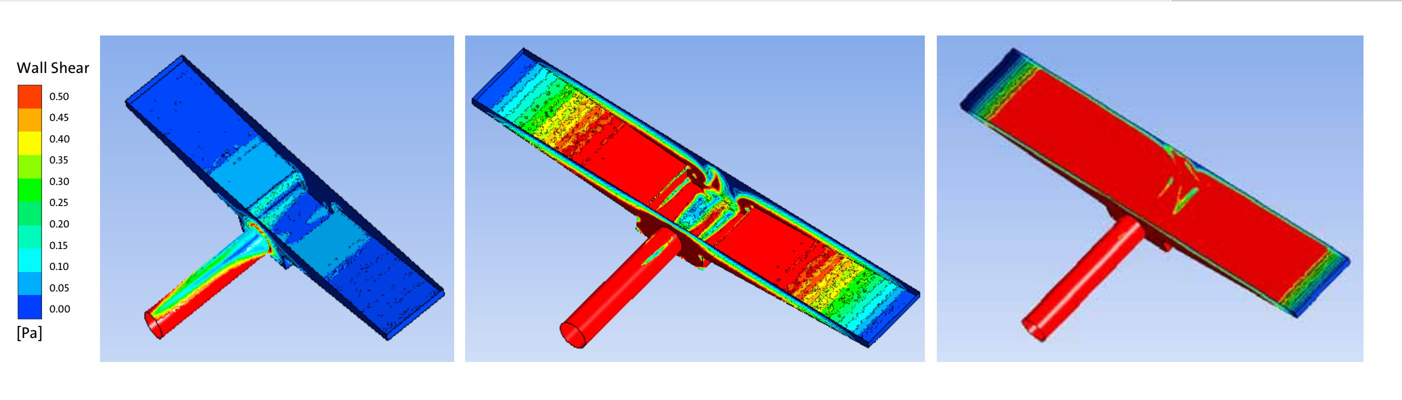


Figure 36:

Bottom shear stress in the sump with a slope of 8% at different outlet flows.
From left 50 l/s, 200 l/s and 400 l/s.

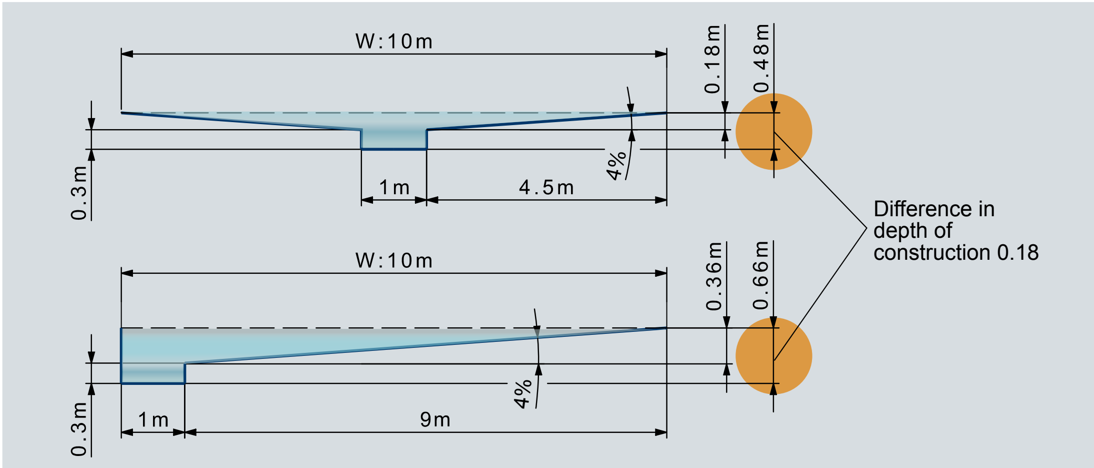


Figure 37:

Difference in maximal depth, depending on where the outlet from the sump is placed.

DEPTH OF CONSTRUCTION

The higher the shear stress that can be obtained in the runoff channel the more certain one can be that material will be carried away. However, the actual slope of the channel will be a compromise between the possible depth and the economics of construction, compared to the ability to obtain self cleaning.

The maximal depth of construction might set the basis for how the sump should be designed; whether the channel should slant to one of the sides of the sump or to the middle (Figure 37).

For several tanks placed together or a tank split in many sections, basically three possibilities of the outlet location exist, as shown in Figure 38, which will result in different construction depths.

As exemplified in Figure 37, the rightmost sump configuration in Figure 38 gives the smallest possible construction depth when using identical slopes in the sumps.

However, even though it is possible to minimise the construction depth by placing the outlet centrally in the sump, other factors might influence this as well. The factors that should be considered are, for example, pipework, material and equipment needed, placement of the adjacent sewer system as well as interconnection between other tank sections when choosing the outlet placement. What will be the best design must be evaluated in each case.

Wall-placed sump
The runoff channel must be designed taking into consideration the water velocity of the arriving water. If the velocity of the water running to the runoff channel is too high and the flow cannot be absorbed by the channel, a reflection wave might arise which will flush water back up on the bottom plate, possibly depositing solids.

On this basis, it could be tempting to create the runoff channel very wide or deep. However, creating a wide channel will lower the water velocity during the final emptying of the channel, which can favour sedimentation in the sump. Making it too deep will on the other hand increases construction costs. As a result, the width and depth of the channel is a compromise between the ability to absorb the flow arriving from the bottom plate, still being able to keep an appropriate velocity, and keeping a reasonable construction price.

Centre sump
During cleaning of a circular tank, the water circulation created will force the water to arrive automatically at the sump due to the outlet flow. In the middle of the circulating water volume, the velocity will approach zero, which results in suspended solids effectively settling at the centre of the tank where the sump is placed.

Independent of whether pumps or gravity are used for emptying the tank, the bottom of the sump should preferably be designed with benches to mimic natural flow patterns and thus prevent sedimentation inside the sump.

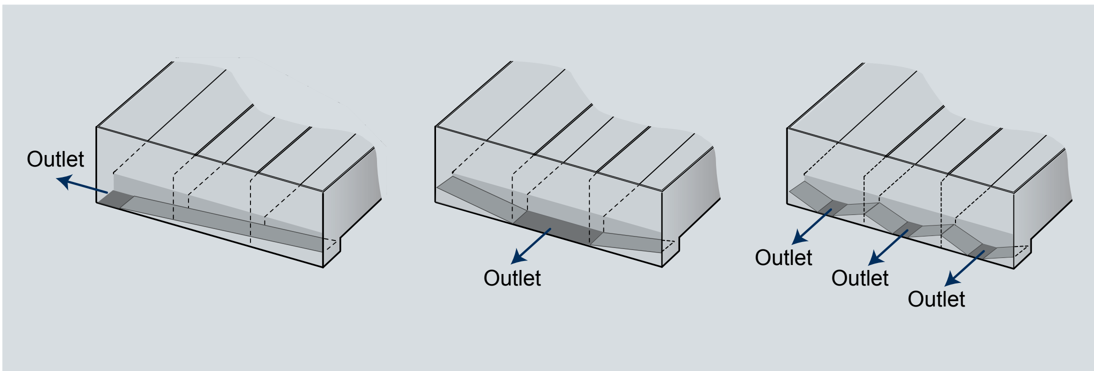


Figure 38:

Different possibilities for placement of the outlet from the stormwater tank.

OPEN/CLOSED TANK CONFIGURATION

Stormwater tanks can either be constructed as *open* or *closed* structures. Choosing one or the other configuration will be a balance between several factors, which usually end up decided by location of the tank. Some of the things to consider when choosing either of the configurations are described below.

Open tanks
Open tanks offer the possibility to easily control conditions in the tank, offer simple inspection of the cleaning process in the tank, and a relatively uncomplicated access to the tank. Ventilation to remove toxic or explosive gases is implicit in the design, although dependant on depth. Besides that there are typically few or no obstructions, such as pillars to support a cover that will interfere with the cleaning jets.

However, there are also consequences which can include inconvenience from noise and odours that affect surrounding areas, and the open tank requires closing off the tank with a security fence, to ensure that people and animals do not fall into the tank.

Closed tanks
Closed or covered tanks offer the possibility for reducing problems due to noise and odour for surrounding areas, avoiding aesthetic inconveniences, and they can therefore be placed in urban areas without putting up security fences to keep people and animals out. Furthermore, they can be designed so that it blends neutrally into the surroundings by placing it underground.

Covering the tank can, however, have the consequence that maintaining a visual control of conditions in the tank is often difficult. Solving such an issue requires installing hatch covers. These must enable viewing into the tank, allow for servicing of machinery, and provide service access for the entire tank (see also the section about Service Access, page 30).

Normally a cover also requires supports in the form of pillars in the tank. These supports create friction for water circulation during cleaning and make a thorough cleaning around these structures difficult. Placement of these ought then to be known in the design phase for the specification of size and layout of Flushjets in the tank, such that these can be placed to minimise dead zones around pillars.

When a covered tank is filled, washed down and emptied with wastewater, there must be effective ventilation that ensures the installation with a change in air volume that matches the changes in water volume, so the construction is not damaged by pressure differences, and which also ensures that gases do not accumulate in critical concentrations of a toxic or explosive character.

The ventilation system should of course be installed to ensure that the speed of air exiting the system does not create an unreasonable level of noise, which in built-up areas may well be regulated. This can be done by building ventilation tracts or openings of a sufficient size between the tank and surroundings, and by ensuring that placement of these create as little disturbance as possible. It may be necessary to equip the ventilation with noise reduction to ensure that operation does not exceed noise levels.

The equipment installed in the tank is exposed to various influences, depending on whether the tank is open or closed. Closed tanks are generally better protected against many influences, whereas equipment in open tanks are exposed to weather such as sunshine, rain, snow, frost, heat and cold.

These extremes affect the installed equipment. This means that attention must be given to these influences, to ensure sensors, pumps (including chains and cables) can handle drying out in direct sun and still be able to function. Pumps can stick or rust. They must also be able to handle frost, or be protected against frost damage. Alternatively, sensors can be used without wired contact, such as ultrasound or radar. Frost can also limit operation, for example with icing-over of the tank or the freezing of equipment. Regular inspection and testing of screens and sluice gates are also necessary.

OBSTACLES

An efficient cleaning of the tank requires a design with a minimum of hydraulic losses in order to minimise the number of dead zones in the tank, and also minimise the energy required to obtain cleaning. Pillars, columns, ladders or other obstacles protruding from the tank floor, walls or cover will increase the losses and create possible dead zones in the tank, and these are areas where undesirable sedimentation during cleaning will take place. Besides altered flow patterns the dynamic cleaning with the sweeping effect of the water jet is also impeded in this case which will compromise cleaning at the corners of the tank (Fig. 39).

If obstacles in the tank cannot be avoided, these must be taken into consideration during the layout of cleaning equipment in order to obtain the optimal cleaning process given the actual conditions.

In some cases the design of the stormwater tank requires that the pump and ejector of the Flushjet must be separately installed. The piping connecting the two parts will create friction losses in the system if mounted directly on the tank floor. Therefore this piping should be mounted 15 - 20 cm above the floor, which will allow detained material to be flushed underneath the pipes and further on to the sump. However supports for the piping will still gather some material during emptying that cannot be flushed away.

The connecting pipes of the Flushjet could ultimately be moulded into the tank floor, which will reduce completely friction losses and dead zones caused by the additional piping and supports and also places where material can get stuck.

SERVICE ACCESS

Regardless of whether the tank is built with or without a cover, the design ought to include the possibility of access to the tank. This makes it possible for:

- General inspection of the tank and cleaning quality
- Cleaning out the tank manually of small stones and the like, which may have slipped by
- Servicing mechanical equipment and other installations, such as Flushjets, pumps, grates and spillways

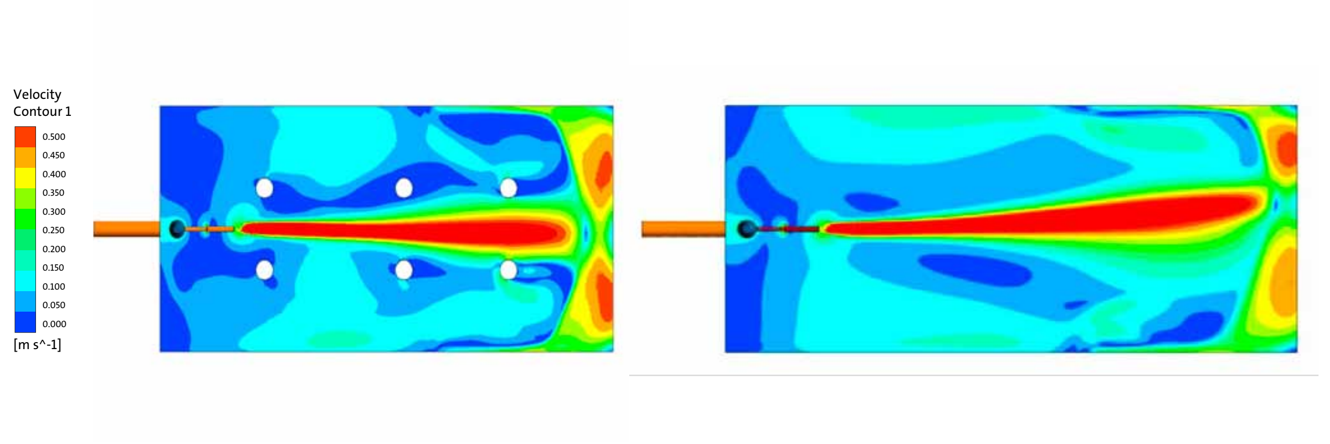
Access to the tank is normally by steps or a ladder, normally mounted permanently in the tank (Fig. 40). Thought should be given to whether the fixed installation will inevitably capture organic matters, fibres, hair, cloths, etc, which can be washed in with storm water. This can make it unpleasant, dangerous and even impossible to use the steps or ladder until they are cleaned.

An alternative is to use hinged ladders, or ladders mounted to floats, meaning the ladder moves in accordance with a rising or falling water level. The ladder is thus kept out of the wastewater and can therefore be used without cleaning in advance.

When designing a facility with a stormwater tank, the handling of mechanical equipment for installation and service should also be thought into the design, with the following points taken into consideration:

Figure 39:

Velocity contour plot 0.15 m above the tank bottom showing the effect on hydraulic flow patterns when the tank has pillars at the tank floor to support the cover. Besides altered flow patterns the dynamic cleaning with the sweeping effect of the water jet is also impeded in this case.



- How is heavy equipment to be lifted?
- Should the lifting equipment be permanently installed or mobile?
- Should pumps be secured to the bottom of the tank or installed on auto couplings?
- At what level is the tank placed above or below terrain?
- How far from the tank edge should mechanical equipment be placed?
- Is vehicle access to the bottom of the tank required?
- Should the tank configuration be open or closed?

Selecting a solution must of course be based upon ensuring a good environment for working and maintenance around the tank.

This needs to be thought into the design from the very first draft, ensuring that the handling of mechanical equipment is dealt with at the start, and how this influences design of the bottom plate, the placement of cleaning equipment and the effectiveness of cleaning.

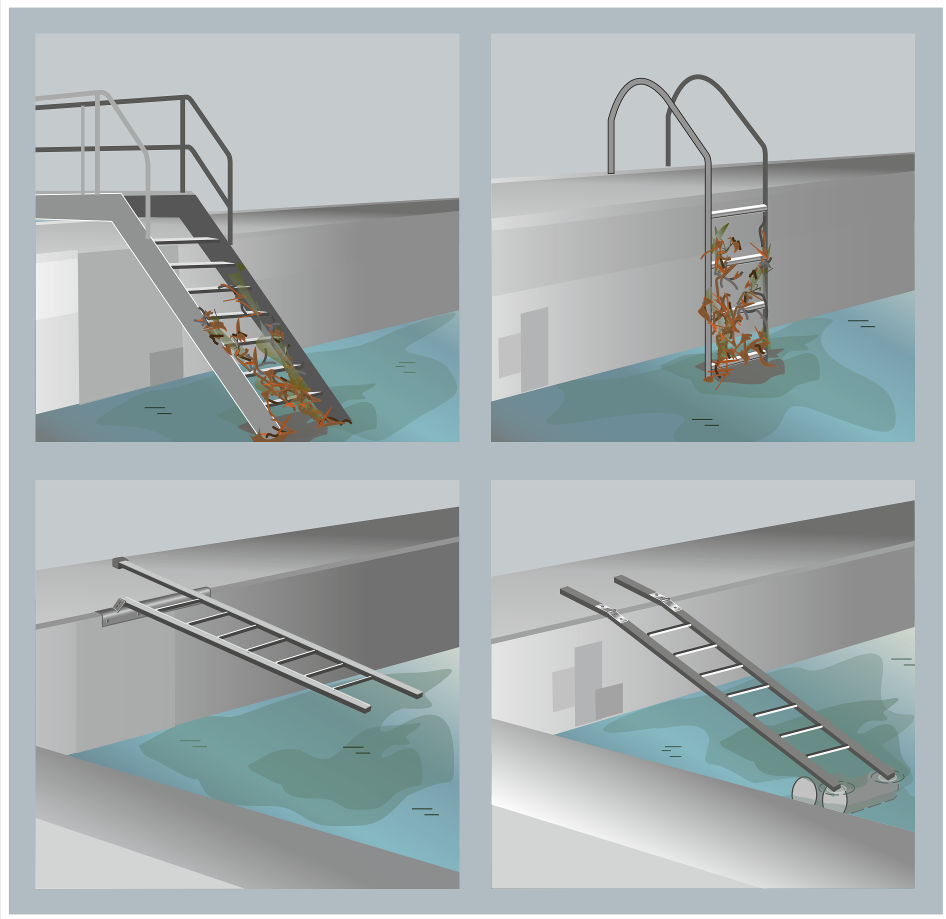


Figure 40:

Different possibilities for installation of ladders at a stormwater tank. Top ones are fixed installations that during storage will be submerged and collect fibrous material from the detained water.

Bottom examples are installations that are able to keep the ladder out of the water either manually by raising the ladder by a hinge or by means of a flotation device mounted on the ladder.

Summary of design criteria for physical layout of tank for cleaning equipment

Based on a summary of the elements described above, the following list extracts some of the most important layout criteria. This list is not exhaustive, as the final layout should also carefully evaluate actual conditions onsite.

- Design the tank dimensions or individual sections so it matches the performance of the cleaning equipment
- Consider water capacity, direction/positioning and number of the inlet(s)
- Consider the amount of sand and suspended solids in the incoming water
- Create benches in corners and along the walls to mimic natural hydraulic conditions
- Create a smooth bottom surface as this will increase cleaning performance
- Avoid obstructions of any kind to minimise dead zones that will favour sedimentation
- Design a sump in connection with the outlet
- Design the sump, connections and outlet system so it is self cleaning
- Let the Flushjets draw in water from the sump to increase flushing time
- Consider intensity of outlet, retention and emptying time
- Consider duty strategy for tank operation

FLUSHJETS

Two types of Flushjets are available for cleaning stormwater tanks; the Flushjet Water/Air (**WA**) and the Flushjet Water/Water (**WW**) (Fig. 41).

The WA ejector is self aspirating and introduces air into the jet flow. By introducing air into the mixing zone, odour levels can be minimised, because formation of anaerobic zones in the tank will be limited. This is necessary if water is detained in the tank for a medium-long period during which biological activity can take place and use up all available oxygen. With the jet provided by the Flushjet WA, this type of ejector is designed to clean tanks with a length/width ratio of ~ 3 (long, narrow tanks).

The Flushjet WW has been developed for the cleaning of wider stormwater tanks than the WA ejector. The WW ejector cleans tanks with a length/width ratio ~ 2. Contrary to the WA Flushjet, the WW Flushjet does not introduce air into the water, but uses all energy to drag in a secondary water flow. It will increase the total ejector water flow and create a powerful jet. As energy is not used to introduce air into the water, the WW ejector has a better mixing efficiency than the WA ejector with the same power input. However, the length of the water jet will be shorter than for the WA ejector due to difference in construction. For that reason the WW ejector is recommended when the retention time of the water is short to medium, or when odour problems will not become an issue.

When the ejector works, the pump provides the primary water flow in the first stage of the ejector. The first stage is constructed with a reduction nozzle inside the ejector pipe or as a nozzle in itself. According to the law of mass conservation and Bernoulli's principle, this reduction creates a depression over the nozzle that in the Flushjet WA will drag down air and in the Flushjet WW will drag in a secondary water flow. The primary water flow mix with the air or the secondary water flow in the ejector and create a strong jet stream for cleaning and the thrust force for mixing the detained water.

The jet length of the ejector is determined by the first stage. A higher flow through the first stage of the ejector results in a greater velocity and head thus a longer reaching water jet. For the Flushjet WA a second stage can be mounted to increase the thrust force produced by the first stage of the ejector. Here a secondary water flow will similar to the Flushjet WW be dragged into the ejector pipe. This additional intake of water will increase the total water flow from the ejector, and thus increase the thrust force.

CONSIDERATIONS FOR SIZING

When sizing Flushjets it is important to consider if the main purpose is cleaning or mixing. When sizing for cleaning purposes, the maximum jet length is the critical parameter, whereas for mixing purposes the thrust force is the critical parameter. However, the application will almost always demand both parameters, and there will most often be a discrepancy between them as shown on Figure 42 and Figure 43. Satisfying both parameters will often result in a trade off with one of them.

Thrust force

In cases where the thrust force is insufficient for the application but the jet dimension fits, two methods can be used to solve this issue.

Either a larger Flushjet with a sufficient thrust force can be chosen even though the jet length will be too long for the tank as long as the jet width still fits the tank. Or installation of one or more mixers to deliver the remaining thrust force to meet what is needed in the application can be a possibility. With the last method the mixers must however be turned off when the water level decreases and the Flushjet must then be able to produce sufficient thrust for mixing the water at this point. Consideration of whether to install additional equipment should however be done before choosing this solution.

Figure 41:

The principles by which a Flushjet WA (left) and Flushjet WW (right) work.

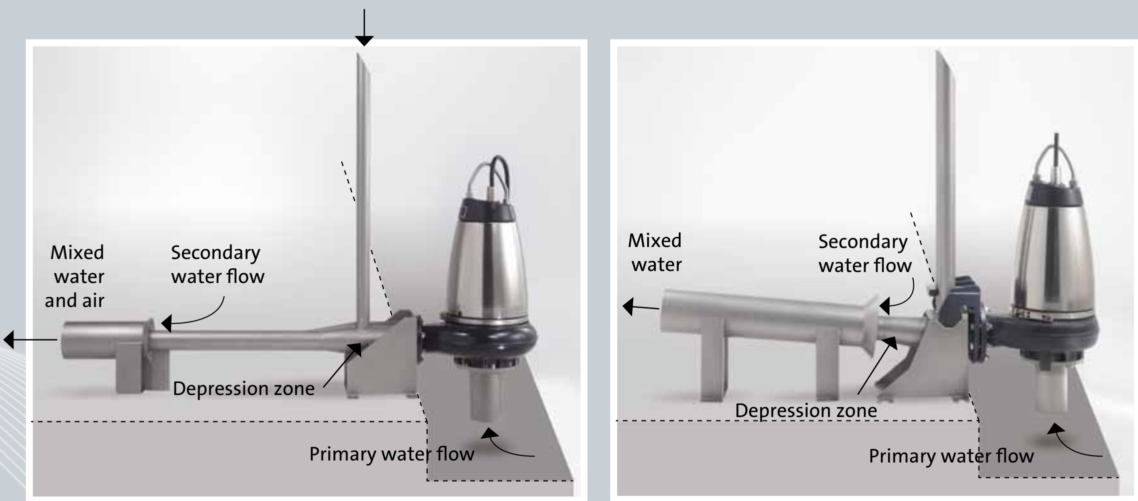
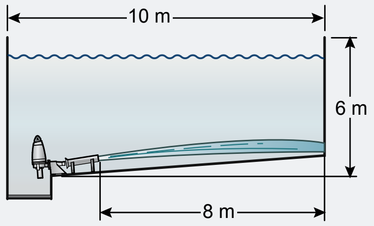
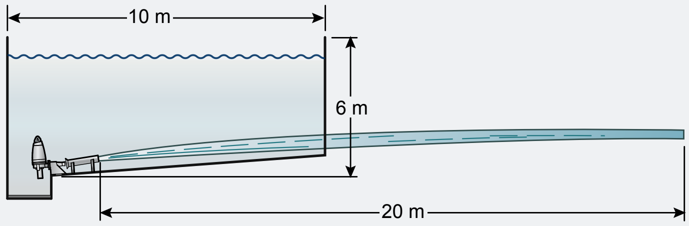


Figure 42:

Considerations of using Flushjets alone or in combination with a mixer.

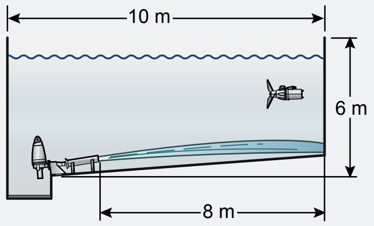


Thrust force needed 650 N Thrust force delivered 300 N		
Jet length	✔	Suitable
Thrust force	✗	Not sufficient



Thrust force needed 650 N Thrust force delivered 650 N		
Jet length	✗	Too long
Thrust force	✔	Suitable

For illustration of the effective jet length produced by the specific Flushjet, the water jet has been shown to penetrate the wall even though this would not possible in reality



Thrust force needed 650 N Thrust force delivered 650 N		
Jet length	✔	Suitable
Thrust force	✔	Suitable

FACTS:

Maximum thrust:
A rule-of-thumb is that with the maximum thrust force delivered by a Flushjet WA or WW, a maximum volume of approximately 1,500 m³ pr. Flushjet can be mixed. However, it depends on the specific application such as tank shape, suspended solid concentration, tank physical design, and so on, and must be evaluated for each application.

JET LENGTH AND WIDTH

There can be situations where the thrust force produced by the Flushjet is sufficient to mix the water but where the jet stream cannot reach the furthest end or cover the entire tank floor (see Figure 43), because of the physical layout of the tank. This can be caused by too steep a slope, an unfavourable ratio between width/length, or result from the direction of the slope and position of the sump and outlet.

These situations can be handled by splitting the tank into different zones or moving the ejector forward to obtain the ideal relation between the performance of a Flushjet and the tank width/length ratio.

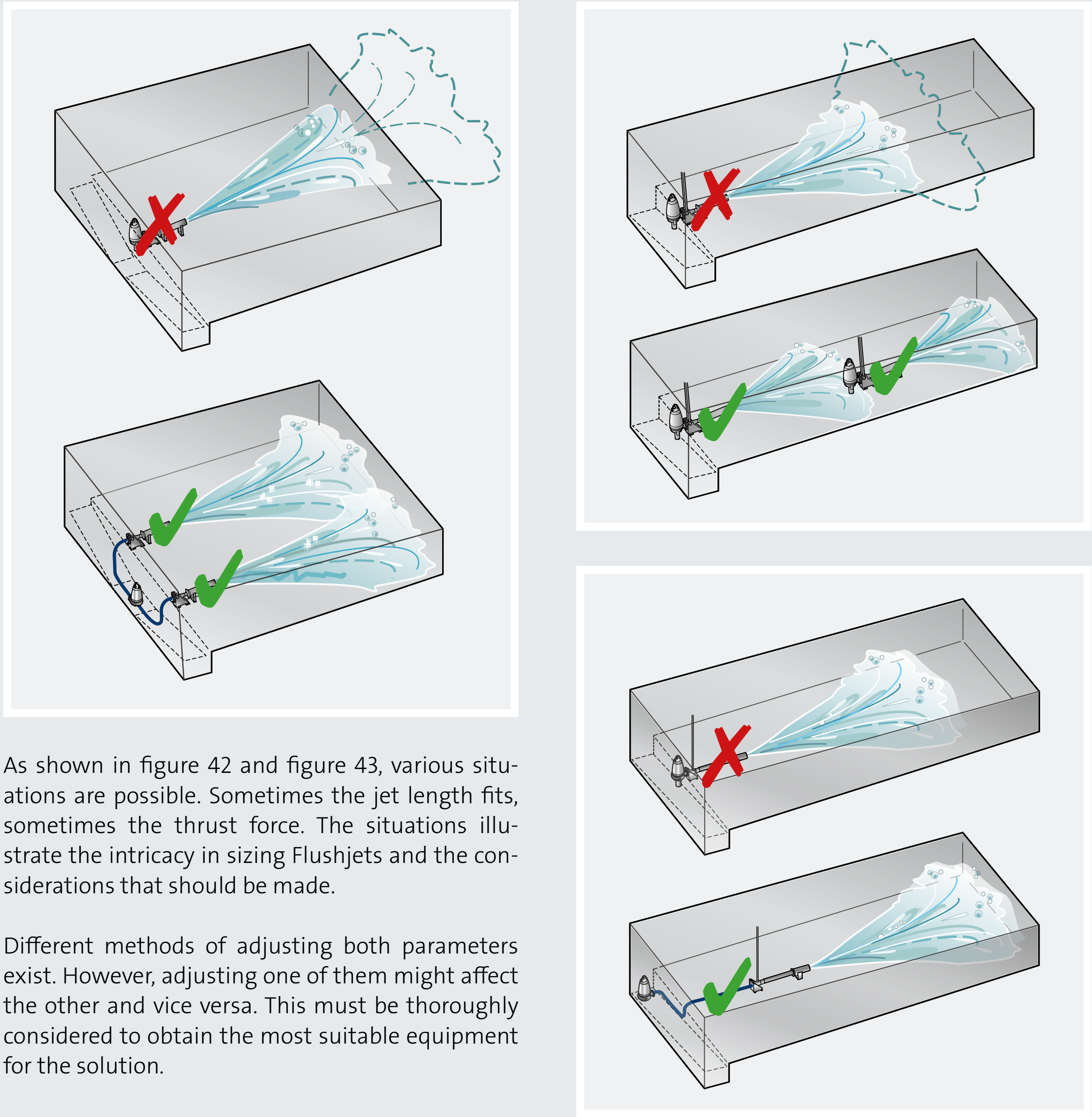
In some cases it is also possible to move the ejector forward in the tank so it is adjusted to the jet ratio of desired equipment (see Fig. 43 bottom (right)). However in these cases it must be checked that the Flushjet can deliver a sufficient volume of water to be able to overcome the necessary bottom displacement forces to drag settled material to the sump (see Figure 19). Furthermore, it must be carefully considered whether flow conditions in the tank will be changed and favour that sediment builds up behind the ejector instead of reaching the sump.

As can be seen on Figure 45, pushing the ejector forward in the tank means that more energy will be wasted at the tank wall instead of being used for mixing and later on cleaning. This wasted energy results in a large area behind the ejector having a low water velocity, where sedimentation of material will be favoured.

However pushing the ejector slightly forward as shown on the simulation in the middle does in this case not affect flow velocities significantly. This could then be a solution for cleaning a tank that has a minor mismatch between actual required cleaning surface and the optimal length to width ratio of the ejector.

Figure 43:

How to overcome unfavourable length/width ratios

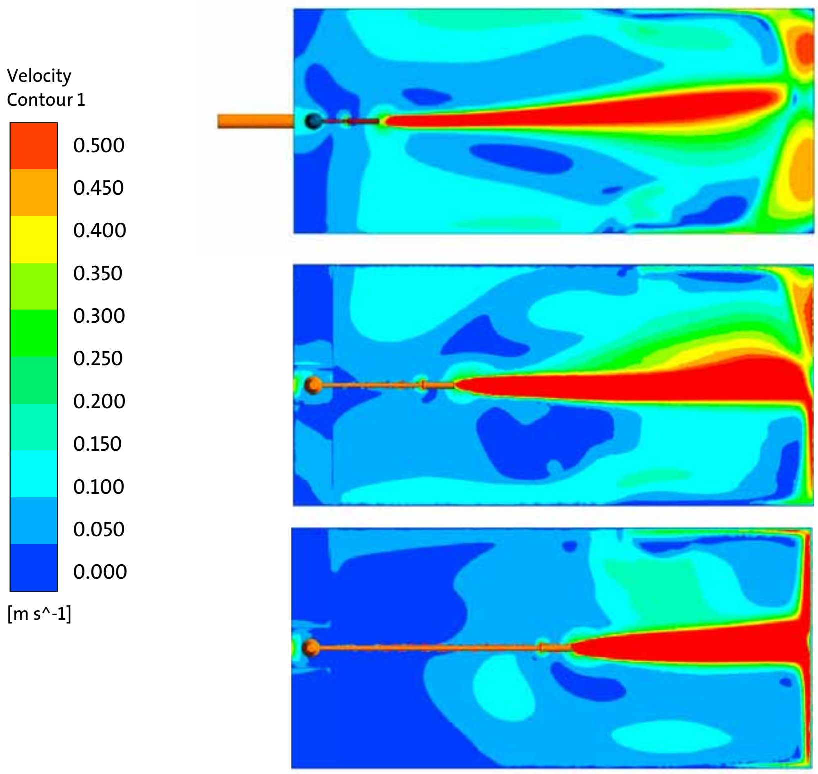


As shown in figure 42 and figure 43, various situations are possible. Sometimes the jet length fits, sometimes the thrust force. The situations illustrate the intricacy in sizing Flushjets and the considerations that should be made.

Different methods of adjusting both parameters exist. However, adjusting one of them might affect the other and vice versa. This must be thoroughly considered to obtain the most suitable equipment for the solution.

Figure 44:

CFD simulation showing how streamlines and possible areas for sedimentation in the stormwater tank change due to different positioning of the Flushjet. Contour plots are shown 15 cm above the bottom plate with the ejector having equal performance in each case.



RECOMMENDATION FOR INSTALLATION AND POSITIONING

Installation of the Flushjet will always be done within the stormwater tank whereas the accompanying pump can be either wet or dry installed. Which is the preferred installation type is individual from project to project. If a wet installation is the choice for the pump it has, besides permanently fixation to the ejector, also the possibility to be coupled to the ejector with an auto coupling (Fig. 45).

For stormwater tanks, various different shapes exist and are still being projected. The following provides a guide of how to place Flushjets in rectangular and circular tanks and gives ideas about how many Flushjets preferentially should be installed. However it is beneficial to have a certain freedom in the Flushjet installation following commissioning in order to adjust it according to the actual conditions in the tank.

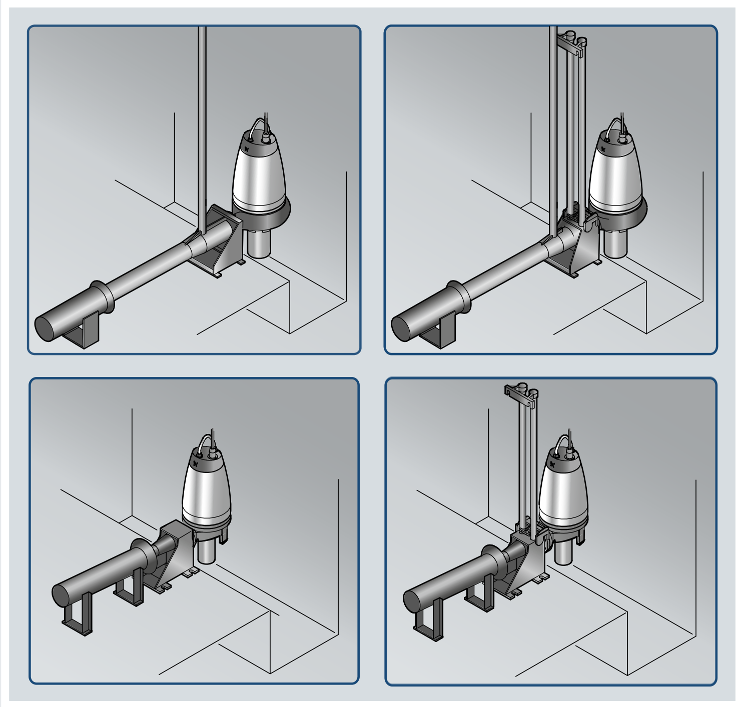


Figure 45:

Fixed (left) and auto coupling (right) mounting on the ejector of a Flushjet WA and WW.

The final selection of Flushjets as well as their exact positioning must be project-specifically handled in each case to obtain the best possible solution for the specific tank.

SELECTION AND SIZING

Inquiries for Flushjets are handled based on customer needs. For selection and sizing of equipment, please find your local Grundfos sales office at:

www.grundfos.com

RECTANGULAR TANKS

Dimensioning criteria for Flushjets
The following key points should be considered when dimensioning Flushjets for rectangular tanks.

- The bottom slope should be between 1-2 % towards the outlet.
- The length/width ratio of the tank if a certain type of Flushjet is preferred or recommended.
- Base dimensioning on jet length and thrust force.
- In tanks with pillars or similar two or more Flushjets should be used and placed to avoid dead zones and resulting sedimentation problems.
- Taking in water from a sump or controlling the outlet capacity can increase operation time for flushing.
- Installation should be made so it can be trimmed according to actual conditions.

Flushjet WA	Floor with a slope of 1 %	Flushjet WW
Tank Dimensions (3:1)	Area [m^2]	Tank Dimensions (2:1)
10x3	30	8x4
121x4	50	10x5
15x5	75	12.6x6
18x6	100	14x7
21x7	150	17x8.5
24.5x8	200	20x10
27.5x9	250	22.5x11
30x10	300	24.5x12
31.5x10.5	350	26.5x13

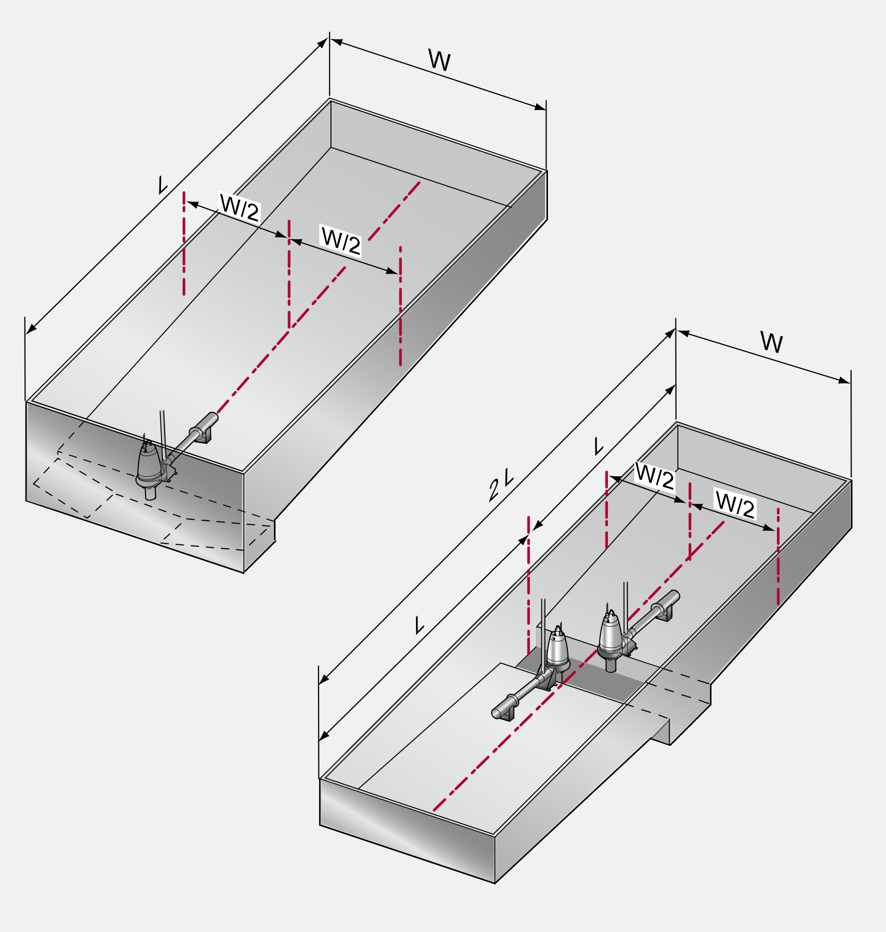


Figure 46:

Principle for placement of Flush-jets in rectangular stormwater tanks

POSITIONING

When designing a rectangular tank the Flushjets can be placed either at one end or in the middle of the tank depending on the tank length and sump positioning (Fig. 46). The bottom slope of the tank should decrease between 1 – 2 % towards the sump.

For the Flushjet WA, the appropriate ratio between length and width should be close to ~3. The Flushjet WW generates a wider jet compared to the Flushjet WA, there-fore the Flushjets WW are more suitable for rectangular tanks with a length/width ratio of ~2. The jet length and width must correspond to the tank dimensions for effective cleaning.

In longer or wider tanks where one Flush-jet does not fulfil the dimensional require-ments, the Flushjets can be placed ahead or besides each other (fig. 47). For wide tanks partitions between different sec-tions might be installed when Flushjets are placed next to each other. This di-vides the tank into more sections that will fill successive as one section at a time is filled before overflow into the next section takes place. This will minimise the need for cleaning the whole tank every time, if only a sub-volume of the tank becomes filled (see Figure 6).

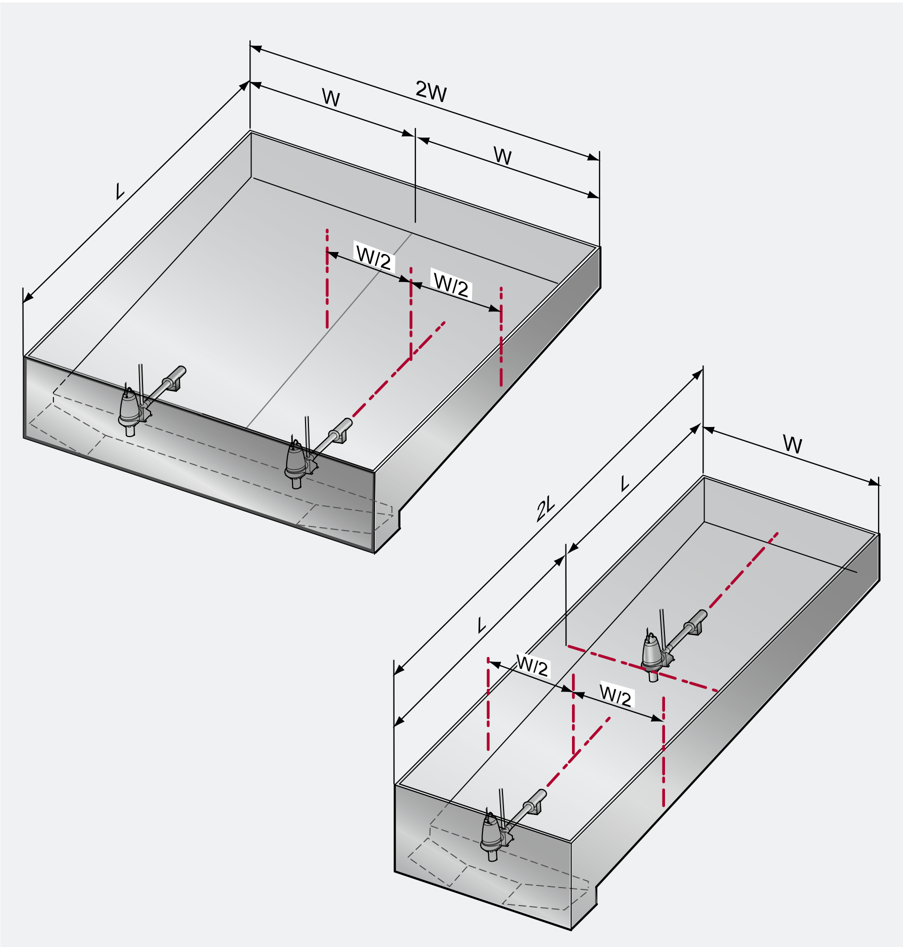


Figure 47:

Principle for placement of more than one Flushjet in wide or long stormwater tanks

CIRCULAR TANKS WITH SUMP PLACED AT THE WALL

For circular tanks with the sump placed at the wall, the tank should be treated as a rectangular tank obeying the length/width ratio of the Flushjets. The tank floor must as for rectangular tanks have a slope of 1 – 2 % towards the outlet/drainage channel.

For diameters larger than one Flushjet can handle, the tank can be split up into two or more zones. For example, when using two Flushjets they should be placed in an angle of around 20° to the centre axis of the tank. Another example of placement of 3 Flushjets are also shown in Figure 49.

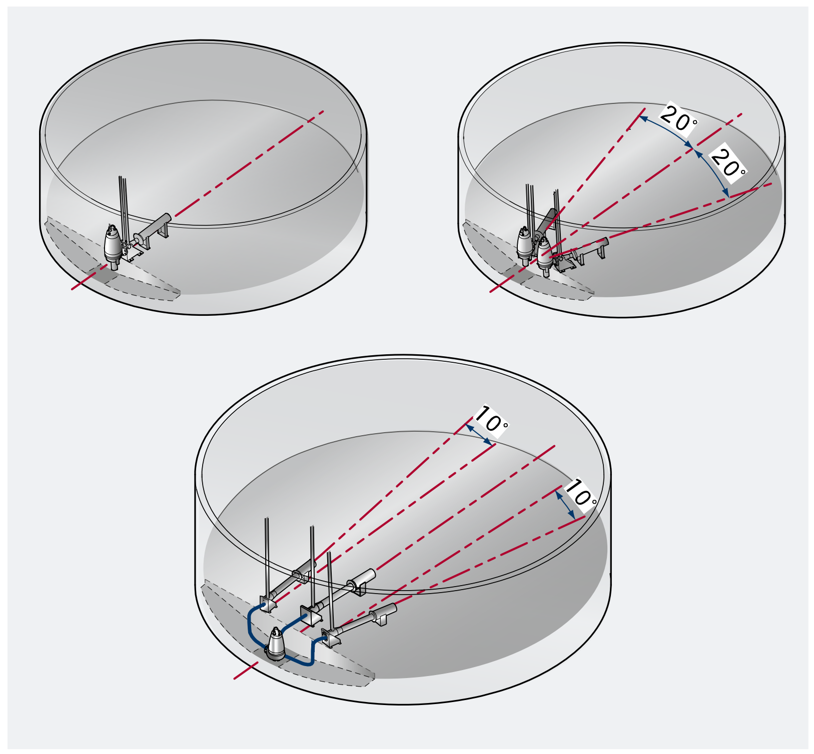


Figure 48:

Principle for placement of Flushjet(s) in circular stormwater tanks with sump placed at the wall

CIRCULAR TANKS WITH CENTRE SUMP

Dimensioning criteria for Flushjets

The following key points should be considered when dimensioning Flushjets for circular tanks with centre placed sump.

Tank diameter	Number of Flushjets*
D < 5 m	~1-2
5 m > D > 15 m	~2-3
D > 15 m	~3-4

* numbers can only be used as a rule of thumb and a careful evaluation of the exact numbers must always be done for each specific installation

- The bottom slope should be around 3-4 % towards the centre sump to optimise the required number of Flushjets.
- Use tank diameter as a guideline to decided the required number of Flushjets to install
- Base dimensioning of the Flushjet on the required thrust force
- In tanks with pillars or similar two or more Flushjets should be used and placed to avoid dead zones and resulting sedimentation problems
- Taking in water from a sump or controlling the outlet capacity can increase operation time for flushing
- Installation should be made so it can be trimmed according to actual conditions.

Positioning

The jet length for the circular tank is less significant than in the rectangular tanks due to water inertia that is created during mixing and cleaning which will create a circular motion (Fig. 49).

For circular tanks with a centre sump the Flushjet should be placed at a distance of 0.4-0.6 times radius from the edge of the tank (Fig. 50). In the direction of flow, the Flushjet should be placed at an angle of 30-60° to the centre axis of the tank. The slope of the bottom should be between 3-4% from the edge to the centre.

This placement offers the advantages of a jet stream that follows the flow direction very smoothly, which per the principle of leverage requires a comparable low energy input. If the suction pipes of the Flushjets are not connected to the sump, flushing until the tank is completely empty is not possible. Moreover the positioning of the Flushjet on the bottom plate obstructs the water flow, and this placement complicates the demands for the secure mounting of cabling, for example. In all, this placement offers good cleaning of the periphery at the cost of risking quality issues in the centre of the tank, if no additional piping or suction is made in the sump, enabling the Flushjet to run until the tank is completely empty or the outlet capacity is so great that the tank will be emptied before the material settles, after the Flushjet has stopped working.

However the Flushjets can also be placed close to the sump or close to the tank wall instead. This placement gives raise to some considerations which are outlined below. Whether to choose one over the other placement for the Flushjets should be evaluated for each specific installation.

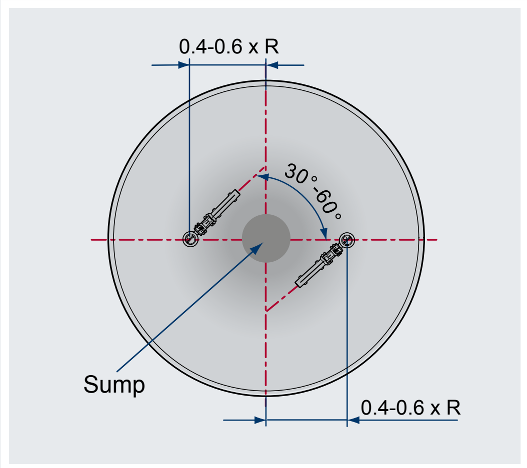


Figure 50:

Principle for positioning of Flushjets in a circular tank with centre sump. R denotes radius.

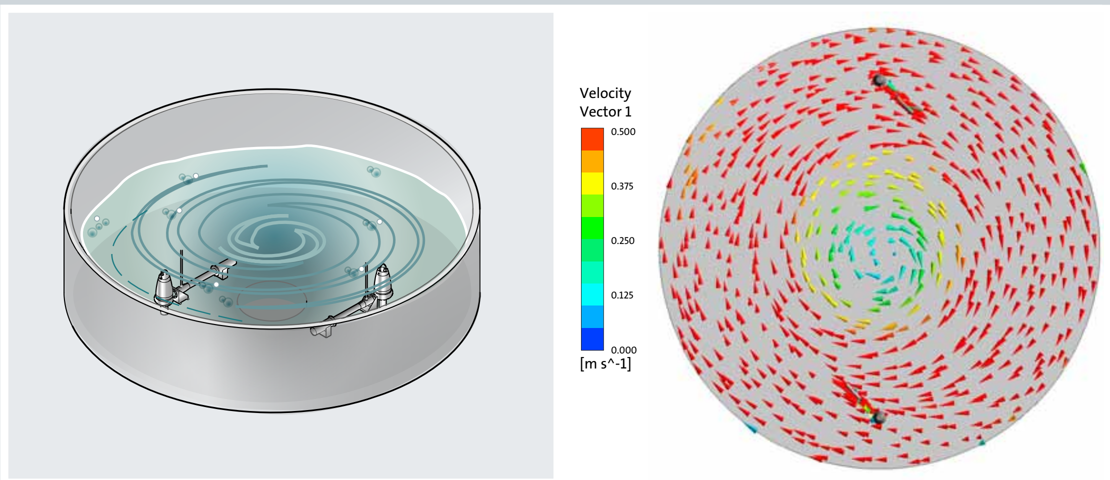


Figure 49:

At the left the principle of water motion in a circular tank.

At the right velocity streamline plot from a CFD simulation of a circular tank with centre sump where the arrow heads indicate flow direction.

Placing the Flushjet close to the sump:
This placement has several advantages, such as the possibility of flushing the tank until completely empty, the absence of obstructions on the bottom plate, and no need for further piping. The short suction pipe results in a low pressure loss, possibly reducing the pump input power. However, the jet flow doesn't follow the flow direction tightly, and thus greater energy is required to get the fluid moving, because of inefficient leverage. Again, this placement complicates the demands for the secure mounting of cabling, for example. In all, this placement ensures good cleaning in the middle of the tank, with the risk of possible quality issues at the periphery.

Placing the Flushjet close to the tank wall:
This placement has the advantages of offering easy access to the Flushjet/pumps as they are close to the tank wall which makes cabling, lifting chains and guide pipes easy accessible, thus with the draw back that when the Flushjet is installed on the bottom plate it obstructs the water flow. This positioning requires least necessary energy to accelerate the fluid as per the principle of leverage. The Flushjets can be installed without additional suction pipes, but then this placement does not allow flushing until completely empty. To be able to clean until the tank is completely empty suction pipes from the Flushjet must be connected to the sump. In all, this placement offers good cleaning of the periphery at the cost of risking quality issues in the centre of the tank.

LAYOUT STRATEGY

When a given tank must be equipped with Flushjets for cleaning, the principle way of thinking is to divide the tank into equal rectangular sub-volumes/areas with a length/width ration of either ~1:2 or ~1:3; depending on type of Flushjet to use. The number of sub-areas that fits into the tank will then correspond to the number of Flushjets to install (Fig. 51).

When doing this, it is important to take the bottom slope and sump placement in to account when splitting the tank into sub-areas. If direction of the slope and position of the sump have not been decided, the division of the tank into sub-areas can then aid in deciding this based on best coverage and cleaning of the tank.

Different variations of tank layouts exist and it not feasible to show positioning of Flushjets in all of them here. However, as an example of the variety, the layout shown in figure 51 below illustrates this.

Here, the Flushjets have been positioned to create a circular movement of the water based on considerations of bottom slope and sump position. The Flushjets have been positioned at an angle so the jet streams create smooth flow conditions without interfering with each other.

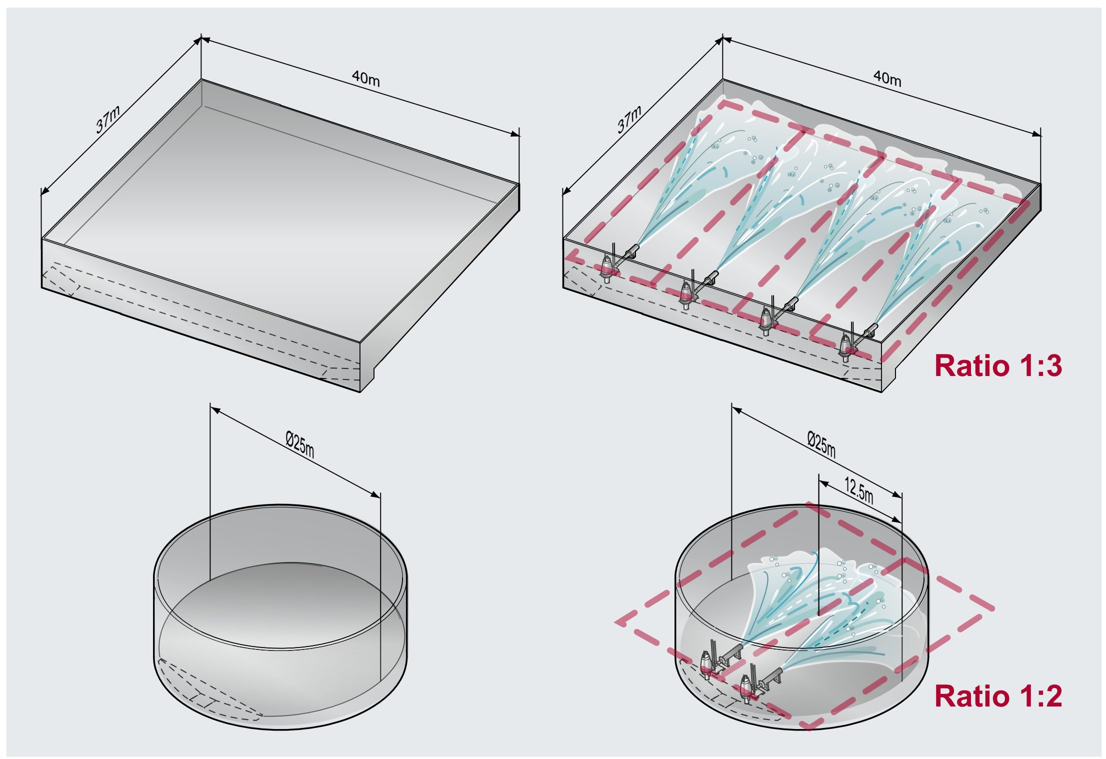


Figure 51:

Exemplification of how to divide the tank area into sub-compartments when planning layout and equipping of stormwater tanks. In the circular tank the ejectors could also be placed closer to the centre angled as shown in Figure 49 to cover the tank area.

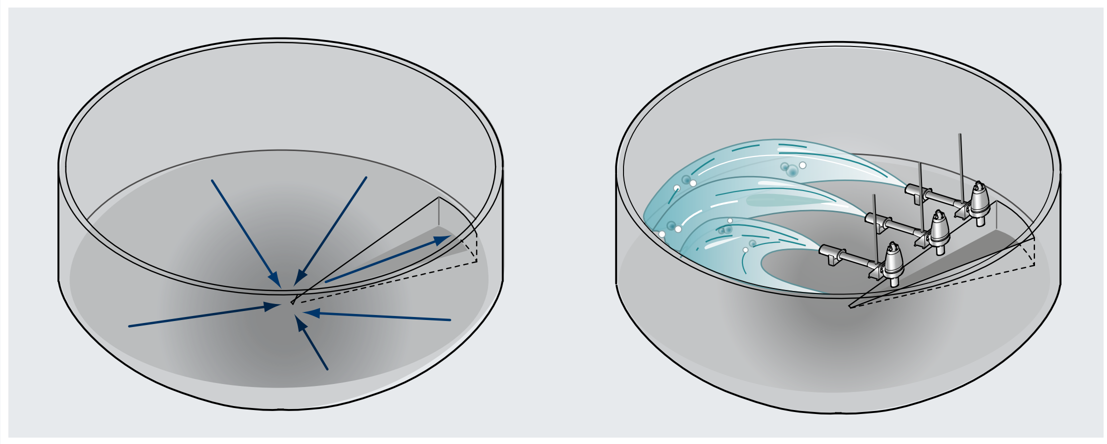


Figure 52:

Placement of Flushjet(s) in circular stormwater tanks with trap sump.

The traversing sump will in this design work as an obstacle to the flow and thereby a catch where suspended solids preferentially will settle and be further conveyed out of the tank.

Furthermore piping from one central pump placed at the tank wall feeding several Flushjets can be installed in the sump without obstructing the flow unnecessarily on the bottom plate, and without creating unintended places for sedimentation of gross material.

PIPING AND MANIFOLD

When placing the ejector and pump of the Flushjet separately either to push ejector units forward, to feed several ejectors with one single pump or to place the pump dry installed, additional piping must be installed between the units.

The additional pipe will increase head losses of the system and result in increased head and decreased flow (H_2, Q_2), and thus, a new pump duty point ($DP_{reduced}$). The increased headloss should be accounted for when selecting the pump for the ejector. As the water volume and hence the flow cleans the stormwater tank, a pump with the original flow (Q_1) and the required head (H_2) must be chosen for the application to have the correct pump duty point ($DP_{required}$) (Figure 54).

PIPE INSTALLATION

Installation of pipes between the pump and ejector can be handled either by placing the pipes above the floor or moulding them into the floor.

Piping placed on the bottom plate with mechanical supports must be placed with sufficient clearance to allow material to pass unhindered underneath; typically this will be at a height so the piping connects directly to the ejector. However, the supports placed on the bottom plate will increase the hydraulic losses and create areas for possible sedimentation. Furthermore if large impurities get trapped under the piping this will create an area where material can build up. On the other hand, as piping is freely available it is fairly easy to disassemble if the piping becomes clogged due to large impurities carried to the tank and thereby restore flow to the ejector.

On the other hand, moulding the pipes in to the tank floor has the advantages that hydraulic losses and additional areas for sedimentation due to protruding piping is complete avoided. However a drawback is the fact that if piping moulded into the tank floor becomes clogged it can be difficult to clean and restore flow to the ejector. In circular tanks, piping placed across the flow direction will, at low water levels, generate a substantial hindrance.

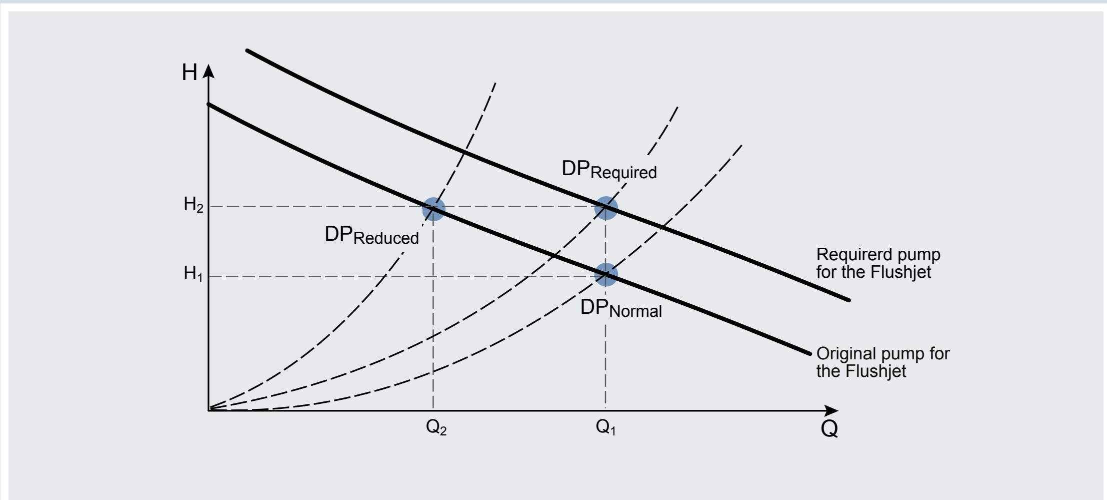


Figure 53:

What to be aware of when placing additional piping between the pump and ejector.

Regardless which solution is chosen, it is important to keep a degree of freedom in the installation at the ejector. This is in regards to the angle of the ejector during final adjustment of the equipment at commissioning based on the actual conditions in the tank. Using adjustable flanges or other initiatives are therefore necessary.

MULTIPLE EJECTORS SUPPLIED BY THE SAME PUMP THROUGH A MANIFOLD

For some applications it could be beneficial to supply multiple ejectors with one single pump. In this case all ejectors must be connected via a common manifold. This can be an issue if space is limited in the sump, if protruding Flushjets in the tank are requested or because of accessibility to equipment. However this solution will raise the issue of having one as opposed to many pumps in the installation.

Using a common manifold to feed all Flushjets with one pump has both pros and cons. As a benefit, the maintenance cost of the system will decrease as less mechanical equipment is installed in the tank. A drawback is that flexibility of system adjustment decreases, as branch pipes are welded in a fixed position to the manifold, so if tank drawings do not correspond to the actual conditions it can be hard to adjust the system. This drawback can to some extent be overcome as described above by using adjustable flanges or other initiatives for final adjustment of the equipment at commissioning.

However using one pump per ejector will give complete freedom for final adjustment during commissioning if this should be necessary. Although several pumps increase maintenance costs, the safety of having more pumps is an advantage in case of pump breakdown. However, as the pump on the ejector manifold can be mounted either on an auto coupling or dry-installed, this safety issue is a matter of estimate.

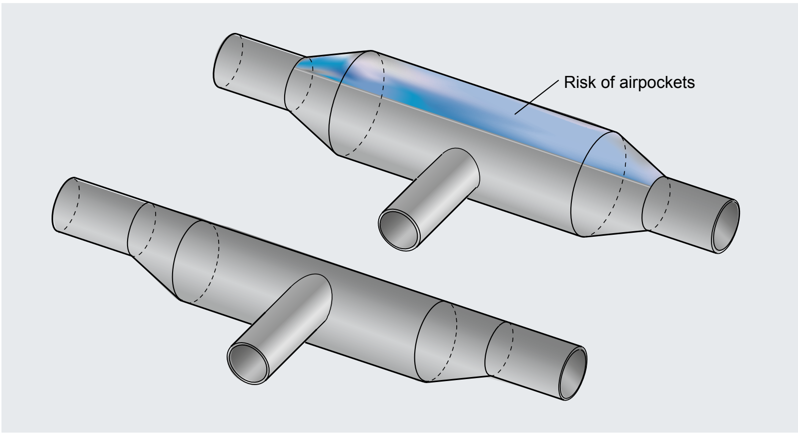


Figure 54:

How to design a manifold without the risk for getting airpockets.

DESIGN OF MANIFOLD

When choosing the solution where more ejectors are supplied through a manifold, there are different things to consider for maximum performance from all Flushjets.

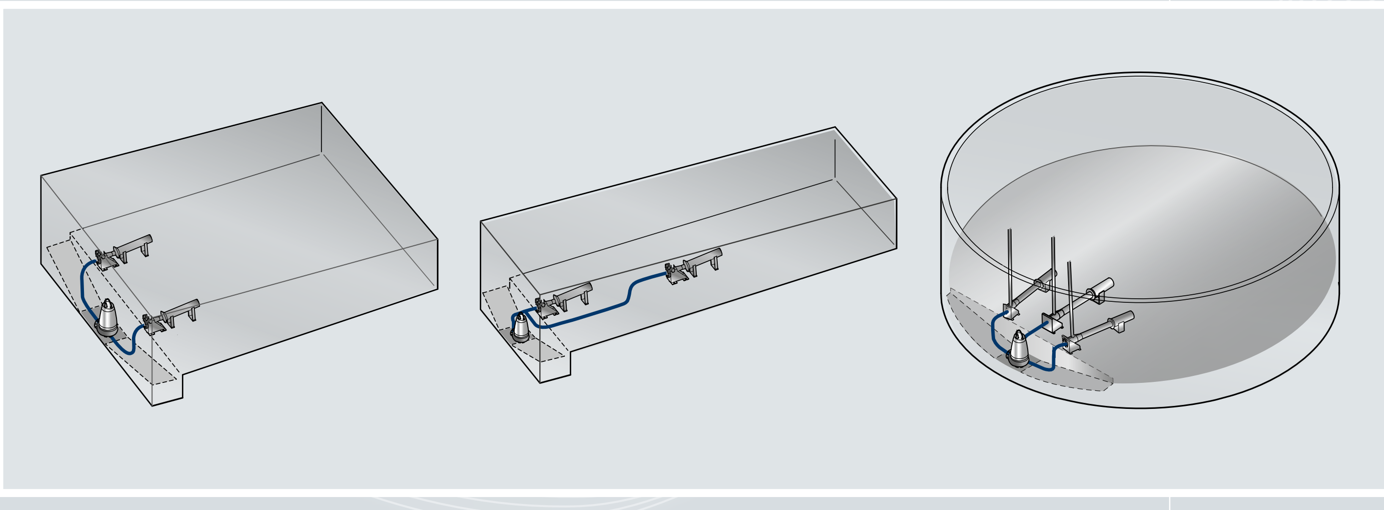
For the components and configuration of the pipe work, eccentric reducers must be used compared to standard narrowings, in addition to placing any offbranching pipes at the top of the manifold (Fig. 54). This design will prevent the possibility for accumulation of air at the top of the pipes, which will otherwise reduce hydraulic capacity of the manifold.

Obtaining equal performance of the different ejectors on the manifold requires that they have the same water flow and hence the same headloss. This is most easily obtained by making the manifold symmetrical if this is possible. Doing this will also simplify calculations and design of the system.

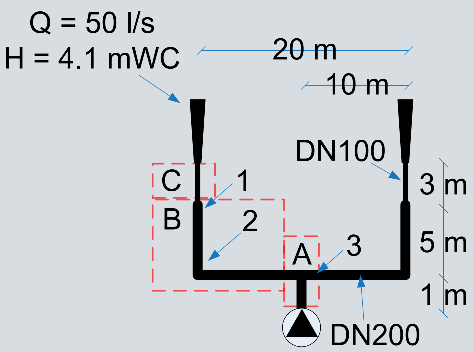
However, the intention in some cases could also be for different performance from each ejector due to tank layout and thus jet length requirements (Fig. 55). Obtaining different performance from the ejectors requires that the piping is laid out accordingly, which can be a source for some rather complex calculations.

Figure 55:

Different layouts where one pump feeds several ejectors. In the left examples the ejectors must have equal performance. In the examples at the right, the ejectors must have different performance.



EXAMPLE:
For a symmetrical manifold each Flushjet must receive 50 l/s at 4.1 mWC to give the required jet length and thrust force. Calculate the pump performance when feeding both ejectors through a manifold with the following characteristics.



All pipes are in stainless steel and the flange of the ejector is DN100. The resistance number of the fittings are as given below:

1: Eccentric reducer (ζ = 0.5)

2: 90° bend (ζ = 0.5)

3: T-piece (ζ = 3)

As the flow is being split into two in the T-piece the pump flow must equal 2×50 l/s = 100 l/s. To find the head of the pump suitable for the system the pipe losses must be calculated and added to the head of the ejector. For these calculations the following equations have been used:

$$H_{single\ losses} = \zeta \frac{v^2}{2g}$$

$$H_{pipe} = f \frac{L \times v^2}{R_h \times 2g}$$

$$v = \frac{Q \times 4}{\pi \times d^2}$$

v : average velocity [m/s]
g : gravitational acceleration [m/s²]
f : friction number [-]
L : distance [m]
R_h : hydraulic radius [m]
Q : flow [m³/s]
d : diameter [m]

Calculation of the headlosses is split into three sections. The headlosses of pipework and single losses for each section have been calculated using WebCAPS (www.grundfos.com).

Section A) from the pump to T-piece where the flow is 100 l/s in a DN200 pipe:
H = 1.57 m

Section B) after the T-piece to eccentric reducer where the flow is 50 l/s in a DN200 pipe:
H = 0.331 m

Section C) after the eccentric reducer to ejector where the flow is 50 l/s in a DN100 pipe:
H = 1.53 m

If the chosen pipe configuration gives unacceptable headlosses, other dimensions could be used and the calculation must be repeated.

The total head of the pump for the system can then be found by adding the losses of the three sections together with the head of the ejector itself.

H_{total} = 1.57 m + 0.331 m + 1.53 m + 4.1 m = 7.53 m

The hydraulic characteristic of the pump must hence be:
Q = 100 l/s, H = 7.53 m

TUBE AND CHANNEL TANKS

Another type of tank also commonly used for storm water detention is the tube or channel tank (Fig. 56). Without going into details this type of tank is basically an over-dimensioned pipe made of a series of connected precast elements of concrete or plastic. Tube tanks are often placed in-line as part of the sewer system with a constant flow also during dry weather conditions, which implies that the bottom of the tube should be designed to handle small and large flows.

Tube tanks should if possible be constructed with a slope that will provide self-cleaning with dry weather conditions and keeping in mind the maximum back water level in the system during stormwater events. However, if it is not possible to obtain self-cleaning of the tube tank, flushing must be used as sedimentation of material will occur during the detention period.

When emptying the tank after the stormwater event, the velocity of the water flowing down the tank can be too low to drag the settled material to the wastewater treatment plant for cleaning. This can be overcome by installing a cleaning system that pumps water from the lowest end of the tank to the highest end where it will increase the water flow down the tube tank.

Properly designed, the additional water flow provided by the pump will increase the bottom shear stress above the critical value of around 3-4 N/m^2 and ensure that settled material at the bottom of the channel will be dragged to the outlet pump from where it is transferred for treatment.

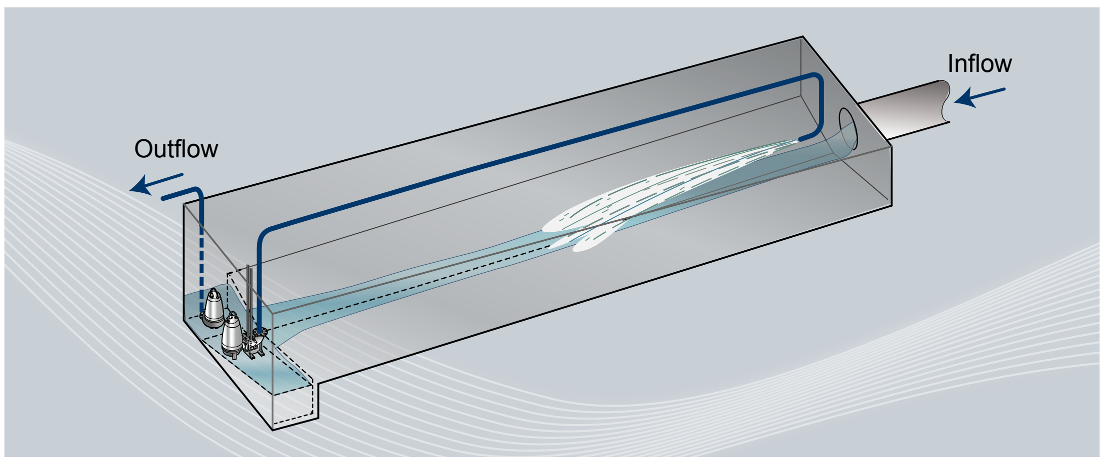


Figure 56:

Sketch of a channel tank for storm water detention

RECOMMENDATION FOR CONTROLS AND SET POINTS

Automatic operation and the control strategy of the stormwater tank can be achieved when controlling and monitoring the action of the different components in the tank based on water levels. Data on water levels can be obtained from any type of level switches/devices installed in the tank and can be used to determine if the level is increasing or decreasing. A controller gathering the data must be able to control the interactions between the installed equipment, with the benefit of obtaining efficient cleaning, maximum hydraulic relief of the sewer system and a reduction of the risk of pollution due to overflow.

Constant water inflow and outflow from the stormwater tank could well be essential. This can be difficult to achieve when the water is conveyed by gravitation, due to differences in water levels. However, pumps controlled by frequency converters can tightly control the flow and keep it constant, independent of water levels. This tight control will especially during outflow from the stormwater tank ensure a constant hydraulic load in the sewer system and consequently a constant flow at the downstream wastewater treatment plant securing treatment conditions.

The operational data from the stormwater tank should not only be used in the tank but also ultimately be transmitted to a central place where the entire sewer system can be monitored. This information helps provide a current status of the system and can additionally be used to plan pre-emptive maintenance of the installed equipment.

Collecting and connecting data from more tanks in the same or different watersheds can be useful for controlling water flows and avoiding overflow from the entire sewer system. Collecting these data can help in getting an overview over which tanks are full or where space is available, if more water should enter the sewer system.

CONTROL STRATEGY

To obtain an effective automatic cleaning of the stormwater tank it is not only sufficient to select the correct equipment. It is also important to have it connected to an intelligent control system managing the filling, depletion and cleaning process. Water levels are used to control operation of the tank where predefined set points based on variations in water levels define the actual control strategy. The principle of control using set points is sketch in figure 57.

Figure 57 is a description of the principles of Flushjet use and consequently does not contain defined levels. The different levels depend on inertia when filling and emptying the tank, and as a general rule adjustments according to the actual operating conditions should be possible. The levels should be defined based on the actual cleaning process, but also out of consideration of minimising energy consumption. The controller must therefore be designed in a way so it is possible to adjust the set points at a later stage.

INCREASING WATER LEVEL

With increasing water levels, the Flushjet should not be in duty. This is to enhance sedimentation of organic and inorganic matter in the tank in case an overflow happens. When inflow ceases and until capacity is available in the sewer system, a steady water level in the stormwater tank is maintained.

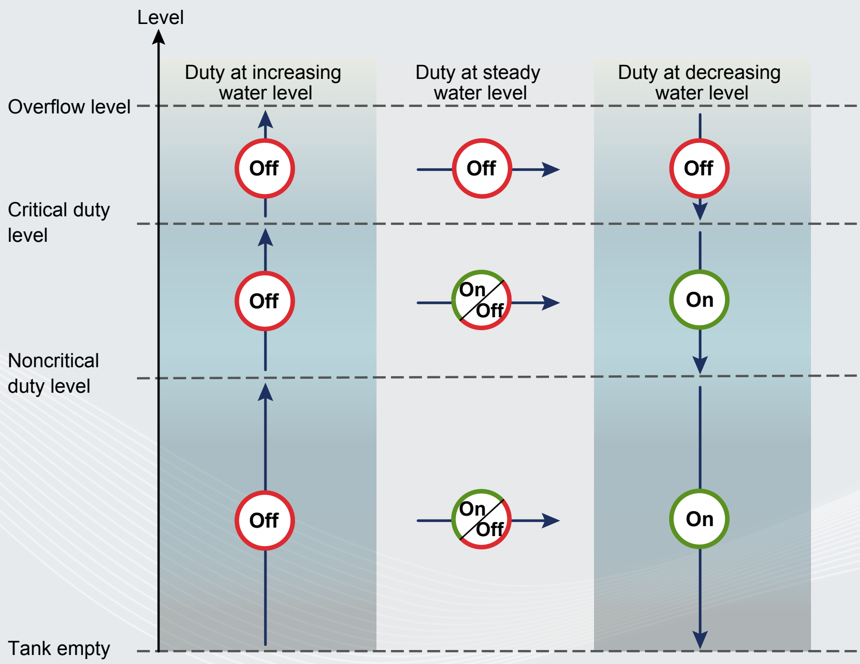


Figure 57:

Control scheme for Flushjets. Blue arrows indicate slope/ trend/gradient of the water level in the tank. The text in the circles indicate specific duty mode of the Flushjet based on variations in water levels.

With a steady water level for a certain period of time, the Flushjet might be run intermittently or continuously for resuspension, avoidance of sedimentation, and to limit odour problems. This should however only be initiated below the critical duty level as water levels above this set point might be critical for overflows, should another inflow take place.

DECREASING WATER LEVEL

With decreasing water level, the action of the Flushjet is strictly controlled by the different water levels. Above the critical duty level equipment will never run. Between critical and noncritical duty level the Flushjet can be run continuously or intermittently to loosen up the settled material that can form relatively solid sediments. When the water level falls to the noncritical level the Flushjet should be running continuously to keep organic and inorganic matter in suspension.

Close to when the tank is empty the Flushjet still runs, but the pump/valve for effluent can be discontinued for a while, giving the Flushjet time to make a continuous flush, dragging all material to the sump for conveyance to the sewer system. This time period should be set according to actual experiences based on conditions in the tank.

BETWEEN OPERATION

Because of the impact of the environment on the installed equipment, it can be an advantage to install as part of the control system function tests and test runs of pumps, sensors, and so on, to ensure full function. Not everything can be integrated into the controls, and it can therefore be necessary occasionally to visually check the tank for foreign items as well as checking overflow grates and the functionality of ventilation, to ensure the required level of operation of the tank.

EQUIPMENT FOR STORMWATER TANKS

Grundfos offers a variety of products for stormwater tank operation. Below is an overview of the products and specifications. More information about the products is available on www. grundfos.com/water-utility

Product:
Flushjet WA/WW

Product types:
Flushjet WA, Flushjet WW

Principle:
Flushjets, with or without intake of air, for automatic and hygienic cleaning of tanks used for temporary storage of storm- or wastewater.

Area: Max. 300 m^2

Thrust: Max. 1500 N

Product:
SL, SLV

Product types: SL1, SLV

Pump principle:
Submersible semi-open, single channel or Super Vortex wastewater pumps.

With or with out built-in controller.

Flow, Q: Max. 87,5 l/s

Head, H: Max. 44 m

Liquid temp.: Max. 40°C

Discharge diam.: DN 65 to DN 150 / 2 ½" to 6"

Product:
AFG/AMD/AMG

Product types:
AFG, AMD, AMG

Pump principle:
Horizontal gear driven flowmakers.

Direct and gear driven mixers.

Axial thrust:

AFG 998-6632 N

AMD, AMG 160-3931 N

Liquid temp.: +5°C to +40°C

Installation depth: Max. 20 m

Product:
SEV, SE1

Product types: SEV, SE1

Pump principle:
Submersible or dry installed single channel or Super Vortex wastewater pumps. Stainless steel versions available.

Controls and protection systems available

Flow, Q: Max. 80 l/s

Head, H: Max. 45 m

Liquid temp.: 0°C to +40°C

Discharge diam.: DN 65 to DN 150 / 2 ½" to 6"

Product:
S-range

Product types:
SV, S1, S2, S3, S4

Pump principle: Super Vortex impeller or channel impeller pumps.

Stainless steel versions available.

Flow, Q: Max. 1800 l/s

Head, H: Max. 110 m

Liquid temp.: 0°C to +40°C

Discharge diam.: DN 80 to DN 800

Product:
KPL/KWM

Product types:
KPL/KWM

Pump principle:
Submersible axial-flow pump.

Flow, Q: Max. 11600 l/s

Head, H: Max. 50 m

Liquid temp.: 0°C to +40°C

Column pipe diameter: 500-2,200 mm

Product:
Controls and Monitoring

Dedicated Controls:
User friendly display, plug and play commissioning and all the right functions.

Supplied as modules or ready-made panels.

Applications are typically sewage network pumping stations controlling up to six pumps.

MP204:
Electronic motor protection.

Dry-running, motor temperature, over- and under voltage or current, power factor and alarm log.

Measured energy consumption.

CUE:
Frequency converters for three-phase pumps. Adjustment of the pump performance to the demand.

Together with sensors, the CUE offers various control modes.

Product:
Remote Management

Grundfos Remote Management:
Internet-based remote monitoring & control for pump systems.

Complete system overview.

Alarms on SMS and email to on duty staff

Full historical event log

Graphical display of trend data and raw data download

Monthly summation reports

Tools for service optimisation

Grundfos WebCAPS

Go to the Grundfos online WebCAPS,
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