Fort Cumberland Storm Tank

a study of optimisation using computational fluid dynamics

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Portsmouth is built on a flat island and as the town has grown in size, the treatment of sewage has become more challenging. Portsmouth is Britain's only island city, lying mostly on Portsea Island. Portsmouth is also one of the most densely populated places in Europe, with the only place in the British Isles that is more crowded being Central London. Like any crowded urban community, its population imposes a heavy burden on the city's network of drains and sewers. All sewers in Portsmouth lead to Eastney Wastewater Pumping Station (WwPS), which is located in the south-east corner of the city. Eastney WwPS handles all of Portsmouth's sewage and plays a critical role in the flood protection system for the city.

Fort Cumberland - Courtesy of Southern Water

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Background

Due to the low number of natural water courses on the flat Portsea Island, most of the excess rainwater drains to the sewage system. Flow from Eastney Wastewater Pumping Station is pumped from Portsea Island to Budds Farm WwTW for treatment. Treated effluent is returned from Budds Farm WwTw to Eastney WwPS and pumped through the Eastney Long Sea Outfall (LSO) to discharge into the Solent.

When the combined flow of untreated sewage and rainwater arriving at Eastney WwPS exceeds the maximum capacity of the transfer pipeline to Budds Farm WwTW, storm flows are screened and pumped (with the treated effluent) through the Eastney LSO. During more severe storm events, the total flow can exceed the capacity of the Eastney LSO and at these times, the excess flow is pumped to Fort Cumberland where it is screened and held in 40,000m^3 storm tanks. When the catchment flow arriving at Eastney WwPS falls below the maximum transfer capacity to Budds Farm WwTW, the Fort Cumberland Storm Tank contents are drained back to Eastney WwPS and transferred to Budds Farm WwTW for treatment (and ultimately returned and discharged via the Eastney LSO).

Large areas of Portsmouth are below sea level, which, combined with the other issues explained, makes it very vulnerable to flooding. Within 20 minutes of a storm event, there can be up to forty times the normal dry weather flow entering Eastney WwPS. This can therefore fill the storm tanks in a short time scale.

The flat nature of the Eastney catchment causes grit and other sewer debris to accumulate within the sewerage system. The arrival of a rainfall event causes a 'first flush' of this material to arrive at

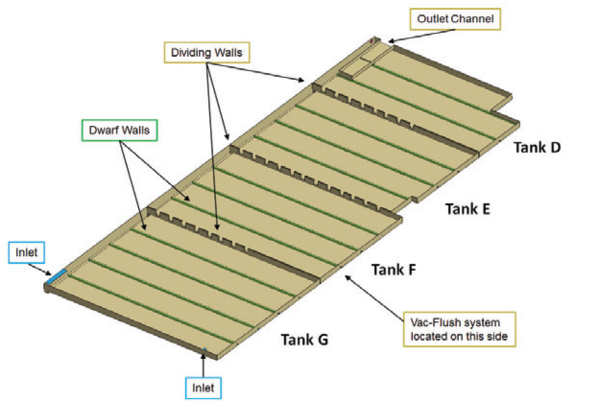


Figure 1: Fort Cumberland storm tanks arrangement Courtesy of MMI Engineering

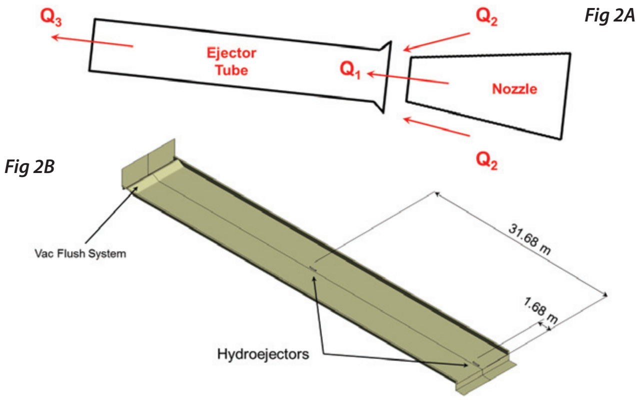


Figure 2: (A) Principal of operation of hydro-ejector. (B) Location of hydro-ejectors in CFD Model - Courtesy of MMI Engineering

Eastney WwPS with the storm water flows. Whilst the pumps at Eastney WwPS are able to handle such solids loads, it has been found that the 6 mm 2D band screens at Fort Cumberland have, during such first flushes, become overloaded.

For these reasons, in 2007 Southern Water announced a £20m plan to provide the city with better protection against flooding. The plan included modifications to the layout and the operational philosophy for the Fort Cumberland Storm Tanks.

A number of options were considered and the favoured option was to introduce the flow from Eastney WwPS into the Fort Cumberland tank upstream of the screens, thereby ensuring pre-settlement within the storm tank before screening.

A programme of work was undertaken in which the proposed modifications were assessed using computational fluid dynamics (CFD). The main areas of work were:

- Estimation of the solids distribution through the storm tank for different positions of the openings in the dividing walls in order to optimise the tank configuration.
- Assessment of the most appropriate means of removing settled solids from the floor of the tank using:
  - Hydro-ejectors or;
  - A Vacflush system at the end of a filling and emptying cycle.

Fort Cumberland Storm Tank

The Fort Cumberland Storm Tank is subdivided in to four tanks as shown in Figure 1 (top left). It was proposed that the storm flow would be received by Tank G.

Dwarf walls are used to create lanes for channelling the flow from the vacflush chambers. The tank has a downward slope of 0.3° along the lanes. Each dwarf wall has a constant height of 0.6 m above the tank floor. Vacflush chambers are located at the upstream end of each lane and at the downstream end there is a channel which collects the fluid and solids after vacflushing.

To investigate the effect on the distribution of solids within the tank of locating new openings in the walls at different elevations, calculations were undertaken with openings located at three different elevations. With the openings at high elevation, dip plates were incorporated on the upstream face of the dividing walls, to investigate the effectiveness of these plates at preventing floatable material from passing through the tanks.

For judging the distribution of solids through the tank, the relative distribution of settled solids is compared.

Hydro-ejectors

Hydro-ejectors operate by discharging fluid from the ejector, therefore generating a jet. Ideally the momentum of the jet will be sufficient to homogenise the solids that are distributed throughout the floor of the storm tank.

If however, there are not a sufficient number of hydro-ejectors operating or the ejectors are not placed appropriately, there will remain regions with settled solids at the floor of the tank.

A schematic of a hydro-ejector and the principle of operation are presented in Figure 2 (top right).

A pump is used to deliver flow (Q1) to a nozzle which is then discharged in to an ejector tube. The flow through the ejector entrains additional flow (Q2) from the tank so that the total flow through the end of the ejector (Q3) is greater than the pumped flow (Q1). In this work the nozzle is considered to be supplied with 120l/s (Q1) and the flow through the ejector tube (Q1 + Q2) is 213l/s.

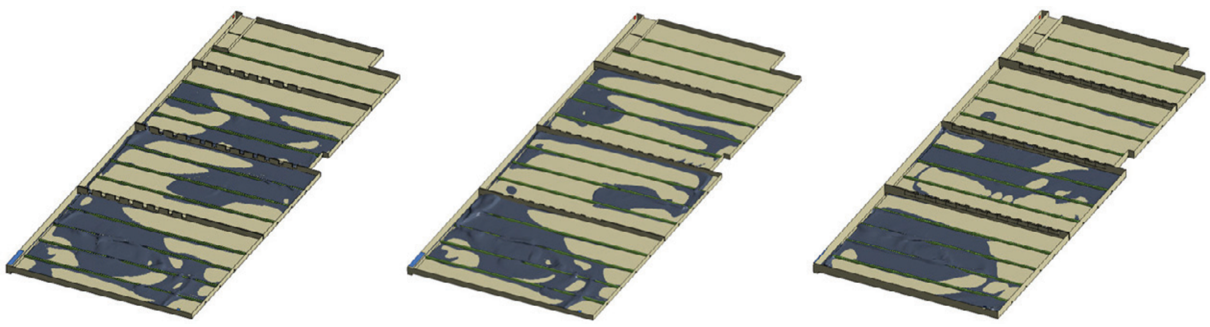


Figure 3: Surfaces of solids concentration at 1000 mg/l, showing the relative distribution of solids - Courtesy of MMI Engineering

Vacflush System

A vacflush system operates by storing a given volume of fluid under a vacuum so that once the tank is emptied, the stored fluid may be released. The fluid travels down the lane formed by the dwarf walls, washing any solids deposited in the lane. At Fort Cumberland, chambers were constructed for vacflush systems, but were never commissioned.

It was proposed that each vacflush chamber would be fitted with a vacuum pump so that under conditions where the storm tank doesn't completely fill, the vacflush chamber will store the maximum quantity of water for optimum flushing of the tank floor.

Solids characteristics

To represent the solids, different particles were considered representing grit particles, tissue and floatable material. The results were as follows:

Solids distribution within the storm tank: Figure 3 (see previous page) presents the distribution of settled solids through the tank following a perceived, worst case storm.

It was found that the distribution of solids was similar for the Low and Medium Level openings, retaining 80% of the solids in the first two tanks (G and F), while the high level openings retained 90% in the first two tanks.

It was also found that the dip plates were effective at retaining floatable material, with almost all being retained in Tanks G and F compared to 40 to 50% with low and medium level openings.

Overall, the results demonstrated the concept of using the storm tank for pre-settlement, allowing fluid to pass on to the screens with a significantly lower solids concentration, therefore potentially allowing the screens to operate as intended.

Hydro-ejectors: An animation of the solids distribution during the operation of the hydro-ejectors is presented below (Figure 4). This shows that during the operation of the hydro-ejectors, a solids load is transported along the floor of the lane directly towards the vacflush chambers.

Some of this solids load could potentially be deposited close to the chamber, which is undesirable as the chamber is located at the opposite end of the lane to where the solids would be removed.

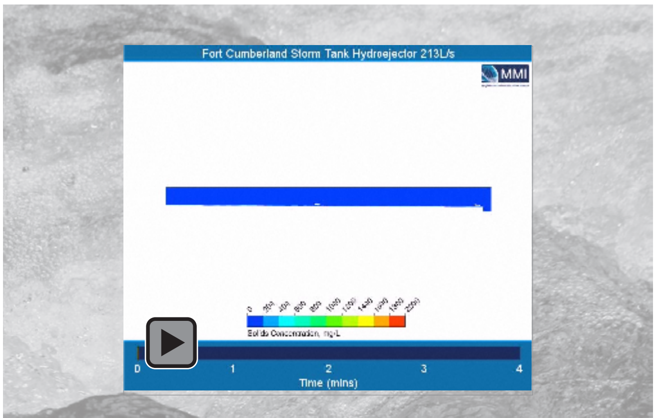
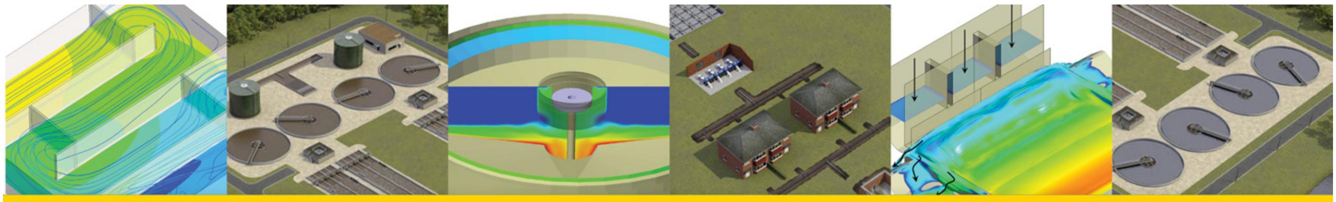


Figure 4: Solids distribution during the operation of the hydro-ejectors Courtesy of MMI Engineering

It was found that a significant proportion of the solids remained unsuspended. The shear stress calculated at the floor of the tank due to the operation of the hydro-ejectors was related back to the shear stress required to mobilise the settled particles. Based on the particle properties, a condition where a significant proportion remained deposited was expected and this was confirmed by the CFD result.



The vacflush system: The animation below (Figure 5) presents the wave of fluid that travels down the lane formed by the dwarf walls within the tank. For a 2,000 micron grit particle, the critical shear stress for incipient motion was calculated to be 1.3 Pa.

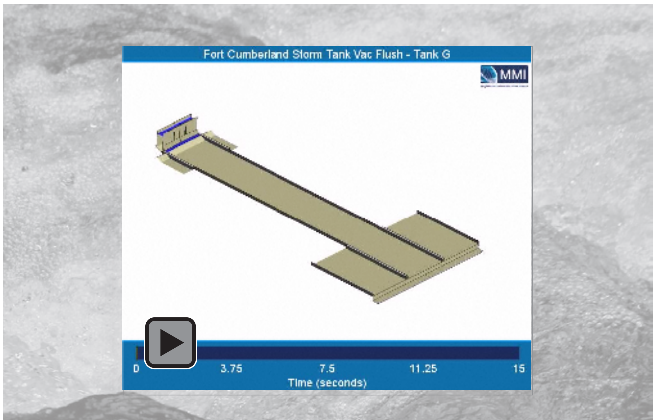


Figure 5: Wave of fluid that travels down the lane formed by the dwarf walls within the tank - Courtesy of MMI Engineering

For self-cleansing of sewers, a minimum shear stress of 2 Pa is suggested in literature and for accumulated mature sediment it is suggested that most deposits should be eroded at a shear stress exceeding 6 to 7 Pa.

Figure 6 (below) shows the bed shear stress that was calculated compared to the critical shear stress for incipient motion of a 2000 micron particle at selected times from the release of fluid.

This demonstrates that the bed shear stress is generally above 10 Pa, and therefore above the critical shear stress for incipient motion of a 2000 micron particle and also for eroding 'mature sediment'.

Summary

The work demonstrated the concept of using the storm tank for pre-settlement, allowing fluid to pass on to the screens with a significantly lower solids concentration, therefore potentially allowing the screens to operate as intended.

CFD modelling also demonstrated that the use of vacflushing was likely to be more successful than the use of hydro-ejectors. The Vacflush chambers were therefore the preferred option and were to be commissioned during the work undertaken to reconfigure the inlet flow to the storm tank.

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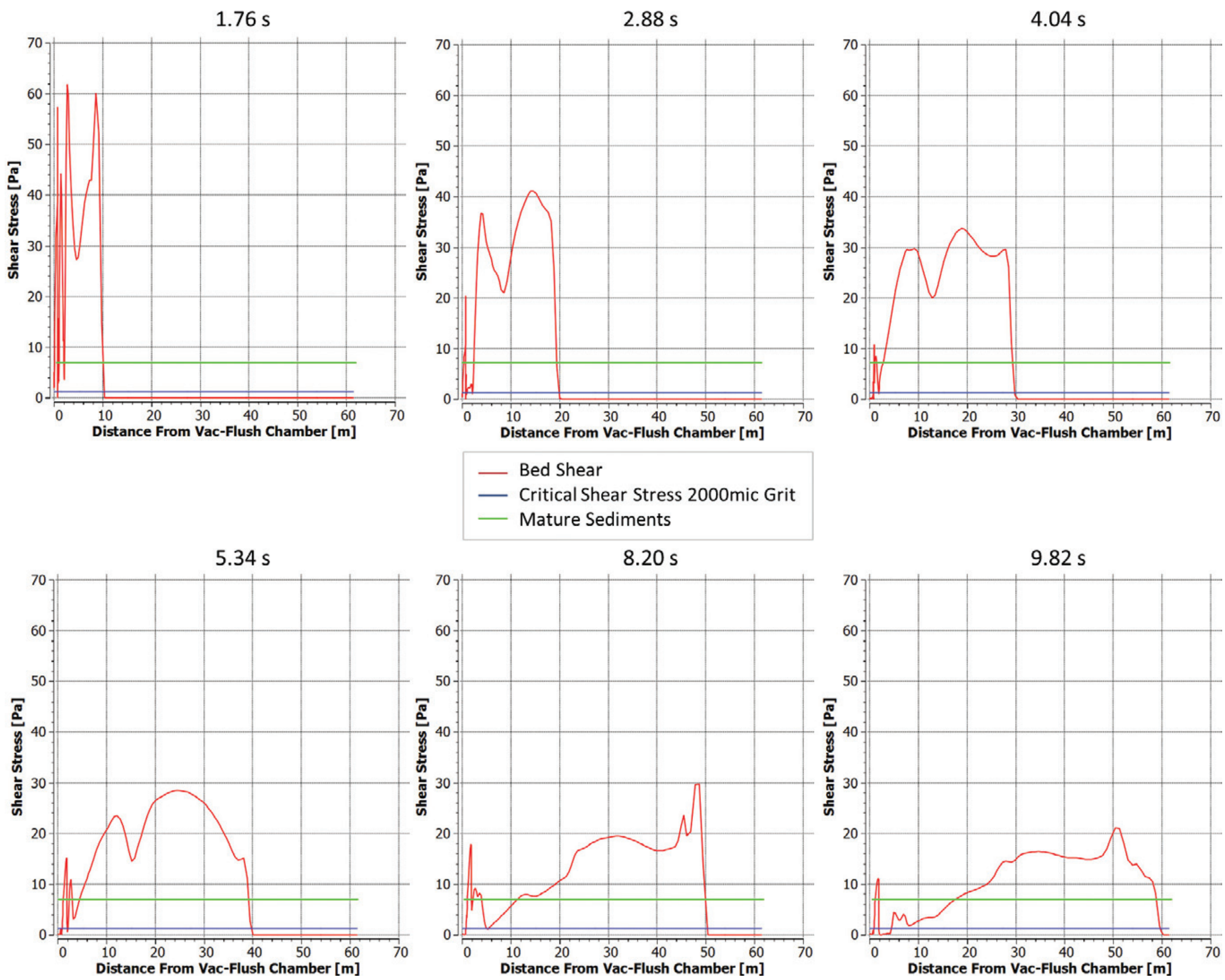

Figure 6: Bed shear stress as a function of distance from the vacflush chamber at selected times from the release - Courtesy of MMI Engineering