Introduction
Computational Fluid Dynamics can be used to generate a computational model of a treatment unit in order to calculate the process performance. The advantage of a computational model developed during the design stage is that optimisation can be undertaken by assessing either geometric changes or process conditions.

In its most basic form, the Activated Sludge Process (ASP) comprises a reactor, into which waste water continually flows, followed by a settling tank to remove the biomass. Some of the biomass is surplus and removed from the system and some is returned back to the reactor. A waste water activated sludge plant includes several operational stages where the hydraulic behaviour is key to achieving optimum efficiency. This includes distribution chambers, anoxic zones and Final Settlement Tanks (FSTs).

Distribution Chambers
In a particular study, due to bedrock, a fairly shallow distribution chamber was designed, which meant that the treatment flow entered through the side of the chamber rather than from underneath as in conventional designs. Initially it was proposed that the Return Activated Sludge (RAS) was introduced at the centre. In order to calculate the flow distribution, a free surface model was used, which resolved the fluid-air interface. The boundary conditions specified at the outlets ensured that none of the weirs were drowned and hence, each was under free discharge. In order to model the activated sludge, the algebraic slip model was used with a hindered settling velocity defined by the Takács [1] equation. A rheology model was used to represent the increase in apparent viscosity with increasing solids concentration. The Stirred Specific Volume Index (SSVI) was conservatively set to 80 mL/g, which represents a good settling sludge and which is therefore harder to mix.

Figure 1 presents the load distribution and the contour plot shows that, due to poor mixing of the RAS, there was an uneven distribution with RAS biased to one side of the chamber. With the RAS inlet repositioned to introduce the RAS into the channel upstream of the chamber, the turbulence within the channel promoted effective mixing, and a good distribution of both flow and solids load was achieved, as shown in Figure 1. It should be noted that good distribution of flow and solids load is important at all stages of treatment. If, for example, there is poor distribution to the FSTs, there may be loss of sludge blanket at higher loadings.

Anoxic Zones
In the ASP, the reactor is typically sub-divided into discrete pockets in which the biological processes can be described as aerobic, anoxic or anaerobic. In anoxic zones, there should be...
no dissolved oxygen. This encourages microorganisms to consume oxygen bound in the nitrates, resulting in denitrification and the release of nitrogen gas. Thus, amongst other requirements, it is usually intended that in an anoxic zone, there is no short circuiting of the flow between inlet and outlet.

An example of an anoxic zone is presented in Figure 2(a). In the original design there were two successive high level weirs, in blue labelled Weir (1) and Weir (2), each at entry and exit to the anoxic zone. To identify short-circuiting of the flow, a ‘dye trace’ experiment was replicated. The advantage of using CFD for dye tracing is that very low concentrations can be measured over very long time scales, which is not easily achieved by similar physical experiments at full scale. Additionally, the average concentration can be monitored over the region of interest, in this case at Weir (2), whereas experiments are limited to monitoring at point locations. The result of the dye trace is presented in Figure 2(b), which shows a significant short circuit. This is shown in the initial concentration which is very high, followed by very low concentration, indicating that the majority of the dye exits very quickly.

In order to improve the design, baffles were introduced in the anoxic zones, as shown in red in Figure 2(a), to divert the flow to low level, therefore generating a longer flow path between the inlet and outlet weirs. The flow paths are annotated in Figure 2(a) with the blue dashed arrow indicating the short-circuit in the absence of the baffle, and the longer flow path with the red dashed arrow which is generated with the baffle. With the baffle, although the dye trace does not show perfect mixing behaviour within the first 0.5 residence times, thereafter, the dye trace curve does follow that of a Completely Stirred Tank Reactor (CSTR), and therefore shows a significant improvement in the hydraulic behaviour.

**Final Settlement Tanks**

After the aeration lane, the waste water undergoes secondary treatment in a clarifier. The activated sludge settles and the effluent passes over a side weir.

Due to the quiescent environment within a FST, effective design of the influent arrangement is key to controlling the hydraulics around the influent to minimise interaction with the sludge bed. Effective inlet design achieves uniform distribution of the flow into the FST and dissipation of the inlet momentum.

As an example, Figure 3 presents views from a series of models of circular FSTs. The first is where the tank design incorporates a stilling drum only. The second includes a McKinney baffle, which is a horizontal baffle below the stilling drum that feeds the flow into the tank in a radial direction at a fixed elevation. The right most view presents a design incorporating an
Energy Dissipating Influent (EDI) which is a drum in to which the influent flows and incorporates a number of ports to swirl the flow on exiting, which assists in dissipating the influent momentum. A schematic of an EDI is presented in Figure 3. Although the analysis was undertaken for steady state conditions, the results clearly demonstrate that, for appropriate influent design, significant improvements in tank performance can be achieved. In analysing the position of the sludge bed, the contour at around 900 mg/L is assessed and it can be seen in Figure 3 that at around this concentration, there is a significant concentration gradient, indicating that this is the approximate position of the sludge bed where a high concentration fluid-solid mixture exists below this contour and a dilute supernatant above. In the latter two designs (McKinney and EDI), there is a significant clearance between the sludge bed and the effluent weir. This not only assists in reducing effluent solids concentrations, but also generates resilience of the tank to surges in flow such as storm events. As an example, Figure 4 presents a hypothetical storm surge received by a FST. In this case, the influent concentration was held constant although in reality, there may be some dilution of the solids. Figure 4 also presents the effluent concentration and the position of the sludge bed over the duration of the storm. (with 0 m being Top Water Level). This shows that, although there was an increase in Effluent Suspended Solids (ESS) concentration during the storm, loss of sludge blanket over the weir did not occur.

References

Figure 4. Response of effluent concentration and sludge bed during storm surge